Information Circular 9060

Fluorspar Availability—Market Economy Countries and China

A Minerals Availability Appraisal

By Catherine C. Kilgore, Sandra R. Kraemer,
and James A. Bekkala

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UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

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I

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environment and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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II

PREFACE

The Bureau of Mines is assessing the worldwide availability of nonfuel minerals. It identifies, collects, compiles, and evaluates information on active and developing mines, explored deposits, and mineral processing plants worldwide. Objectives are to classify domestic and foreign resources; to identify, by cost evaluation, resources that are reserves; and to prepare analyses of mineral availabilities.

This report is part of a continuing series of reports that analyze the availability of minerals from domestic and foreign sources and the factors affecting availability. Questions about these reports should be addressed to Chief, Division of Minerals Availability, Bureau of Mines, 2401 E St., N.W., Washington, DC 20241.

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

gal/d	gallon per day	mt	metric ton
gal/min	gallon per minute	mt/d	metric ton per day
ha	hectare	mt/yr	metric ton per year
km	kilometer	pct	percent
km^2	square kilometer	st	short ton
lb	pound	tr oz	troy ounce
m	meter	wt pct	weight percent
m^3/h	cubic meter per hour	yr	year

FLUORSPAR AVAILABILITY—MARKET ECONOMY COUNTRIES AND CHINA

A Minerals Availability Appraisal

By Catherine C. Kilgore,[1] Sandra R. Kraemer,[2] and James A. Bekkala[2]

ABSTRACT

The Bureau of Mines investigated the availability of fluorspar (CaF_2) from 36 U.S. and 50 foreign mines and deposits in 13 countries. Only 6 U.S. properties are considered to be economic, as 29 domestic deposits were found to have an average total cost of production that was uneconomical at a breakeven (0-pct) discounted-cash-flow rate of return (DCFROR). The 50 foreign properties evaluated represent at least 85 pct of demonstrated fluorspar resources located in market economy countries and China. All evaluated foreign operations were found to be economic to marginally economic in January 1984 dollars when compared against published prices for each country.

Reserves for 56 properties totaled 97 million metric tons (mt) (recoverable CaF_2) from demonstrated ore resources of 344 million mt that contained 123 million mt CaF_2. The average total cost needed to cover all costs over the life of each operation was determined for all recoverable fluorspar products.

Comparisons of mining, beneficiation, and transportation costs per metric ton of fluorspar concentrate illustrate advantages between countries. Of the three countries with the greatest fluorspar production, China, with its high-grade, low-cost operations had the lowest weighted-average total cost of production ($38/mt concentrate). Mexico was next, at $54/mt concentrate, and benefited in U.S. dollar terms from the devaluation of the peso. The Republic of South Africa needed an average of $90/mt of concentrate to cover all costs of production at its large low-grade deposits.

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INTRODUCTION

The purposes of this report are to identify and define fluorspar resources and to evaluate the production potential and important factors affecting availability of fluorspar from U.S. and foreign properties. For this study, the Bureau of Mines analyzed the engineering and economic availability of fluorspar from 14 countries, including the United States. The objective was to cover at least 85 pct of the fluorspar resources in market economy countries (MEC's) and China; China was included because it has become a major supplier of fluorspar to the United States since 1981. With the prominent countries selected, the next objective was to cover at least 85 pct of known resources from producing and nonproducing operations and undeveloped deposits within each of these countries. The mines and deposits evaluated and their current status, mining and beneficiation methods, and products recovered are summarized in table 1. Ownership tables can be found in appendix A.

Of the numerous domestic deposits known, 43 were originally investigated; 7 of these were excluded from this evaluation because technology to process the ore does not exist, or resource tonnages were reported as inferred rather than demonstrated, or the demonstrated resources as of January 1, 1984, were considered to be negligible or depleted. Deposits excluded from this study are listed in appendix A.

Only six domestic operations are compared with other world operations, owing to the "marginal to subeconomic"[3] nature of the majority of the domestic resources. The Bureau of Mines 1985 Mineral Commodity Summaries (*28*)[4] lists these six operations as the domestic reserves. Four of the operations are owned by Ozark-Mahoning and are in Illinois; J. Irving Crowell owns a mine in Nevada; and D & F Minerals Co. owns one in Texas.

Of the 56 domestic and foreign operations analyzed, 46 were in production during January 1984, 3 were temporarily shut down, 1 was in development stages, and 6 were undeveloped. All 56 properties were compared together, as all were found to be economic or marginally economic. Nonproducing and undeveloped properties are included with producing operations in all analyses, because development decisions appear to rely on finding consumers more than on the cost of production. The current slow market conditions have caused a reduction in production at most operations, leaving little room for new operations.

The procedure for this study was to identify recoverable resources and engineering and economic parameters that would affect production from the deposits selected for evaluation. Dames & Moore gathered information on 50 foreign properties under contract J0225010 (*7*). This involved meeting with company officials and, in most cases, actual site visits by contract personnel to obtain information. Domestic deposit information was collected by personnel at Bureau of Mines field operations centers. Demonstrated and identified resources and commodity grades were defined; capital investments and operating costs (direct and indirect) for the appropriate mining and beneficiation methods were obtained or estimated; transportation costs to known market or port areas were assessed; and a cost evaluation for each deposit was performed. Finally, the individual deposit evaluations were aggregated to show potential fluorspar availability for acid, ceramic, and metallurgical grades at various long-run constant dollar commodity prices.

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METHODOLOGY

The Bureau of Mines is developing a continuously evolving methodology for the analysis of long-run mineral resource availability. An integral part of this system is its Supply Analysis Model (SAM) (*6*). This interactive computer system is an effective mathematical tool for analyzing the effects of various parameters upon the economic availability of domestic and international resources.

For each operation included in this evaluation, capital expenditures were calculated for exploration, acquisition, development, mine plant and mine equipment, and constructing and equipping the mill. The capital expenditures for the different mining and processing facilities include the costs of mobile and stationary equipment, construction, engineering, infrastructure, and working capital. Infrastructure is a broad category which includes costs for access and haulage facilities, ports, water facilities, power supply, and personnel accommodations. Working capital is a revolving cash fund required for operating expenses such as labor, supplies, insurance, and taxes. All costs were in U.S. dollar terms.

The initial capital costs for producing or past producing mines and developed deposits have been depreciated according to the actual investment year, and the undepreciated portion was treated as a capital investment in 1984, the year of costs for this evaluation. Reinvestments will vary accord-

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[3] Marginal to subeconomic is defined as needing a price greater than the current market price but less than 1.5 times the current price (lowest cost operation was 1.1 times the market price). Subeconomic resources requiring a price greater than 1.5 times the current market price are listed in this evaluation as Other Resources.

[4] Italicized numbers in parentheses refer to items in the list of references preceding appendix A.

Table 1.—Fluorspar properties and associated production status, mining and beneficiation methods, and products recovered

Country and property name	Production Status	Production Years	Mining method	Beneficiation method	Product recovered
China:					
Da Gai Tang mines, Hua De mill	P	27	Shrinkage	Flotation	Acid, metallurgical.
De An District	P	23	Open pit	..do	Acid, metallurgical, ceramic.
Hei Shao Tou Mine, Bai Yun He Pe mill	P	55	Shrinkage	..do	Acid, metallurgical.
Hong An District	P	33	Descending crosscuts	..do	Do.
Pong Lai mines, Fu Shan mill	P	49	Shrinkage	..do	Do.
Pong Lai mines, Xian Shan mill	P	49	..do	..do	Do.
Wu Yi District	P	29	..do	..do	Do.
France:					
Escaro	P	10	Open pit	..do	Acid.
Fontsante	P	4	Shrinkage	..do	Do.
Le Burc	P	7	Top slicing	Heavy media	Acid, metallurgical.
Montroc	P	9	Open pit	Flotation	Acid, ceramic.
Morvan District	N	20	..do	..do	Acid.
Rossignol	P	26	Shrinkage	Heavy media	Metallurgical, barite.
Germany, Federal Republic of:					
Clara	P	W	W	Flotation	Acid, barite products.
Kaefersteige	P	W	W	..do	Acid.
Italy:					
Domusnovas	N	8	Open pit	..do	Do.
Mineraria Silius	P	18	Sublevel	..do	Acid, metallurgical, lead, barite products.
Pianciano	N	17	Open pit	Gravity	Metallurgical.
Kenya: Kenya Fluorspar Co.	P	24	..do	Flotation	Acid.
Mexico:					
El Realito (Rio Verde)	P	18	Stoping with fill	..do	Acid, metallurgical.
El Refugio (Rio Colorado)	T	17	..do	..do	Acid, metallurgical, ceramic.
Fluorita De Mexico	P	19	Room and pillar	..do	Acid.
La Domincia	P	14	..do	..do	Do.
Las Cuevas	P	17	Shrinkage	..do	Acid, metallurgical.
Minas De Navidad	P	11	..do	..do	Do.
San Francisco del Oro	P	9	..do	..do	Acid.
Zinc de Mexico	P	4	Hydraulicking	..do	Do.
Morocco: El Hammam	P	7	Shrinkage	..do	Do.
Namibia: Okorusu	N	11	Open pit	..do	Do.
South Africa, Republic of:					
Buffalo Fluorspar	P	17	..do	..do	Acid, metallurgical, ceramic.
Kruidfontein	N	24	..do	..do	Do.
Marico Fluorspar	T	33	..do	..do	Acid.
Transvaal Fluorspar	N	21	Room and pillar	..do	Do.
Vergenoeg	P	52	Open pit	..do	Do.
Witkop	P	54	..do	..do	Do.
Spain:					
Fluoruros	P	12	Open pit, room and pillar	..do	Acid, metallurgical, ceramic.
Gijon Area	P	25	Room and pillar	..do	Acid, ceramic.
Mina Ana, Torre mill	P	26	Room and pillar, open pit	..do	Do.
Minas de Orgiva	T	29	Room and pillar	..do	Acid, ceramic, lead.
Thailand:					
Thaivat Mining Co. (Tao Dam mine, Ban Lard mill).	P	5	Shrinkage, open pit	..do	Acid.
Mae La Luang	P	10	Open stope	Sizing	Metallurgical.
Mae Tha District	P	3	Open pit	Heavy media	Do.
Phanom Thuan District	P	4	..do	Sizing	Acid feed[2], metallurgical.
Salak Pra	P	4	Open pit, open stope	Handsorting	Do.
SK Minerals	P	4	Open pit	Flotation	Acid.
Takien Ngam	P	33	..do	Handsorting	Metallurgical.
Tunisia: Hamman Zriba	P	46	Room and pillar	Flotation	Acid.
United Kingdom:					
Blackdene mill and mines	P	27	Shrinkage	..do	Acid, lead.
Broadwood mill and mines	P	16	..do	..do	Acid, metallurgical, lead.
Derbyshire Deposits (Laporte)	P	6	Sublevel stoping	..do	Acid, barite, aggregate.
United States:					
Annabell Lee	N[3]	11	Shrinkage	..do	Acid, lead, zinc, aggregate.
Barnett	P	9	..do	..do	Do.
Denton	P	10	Room and pillar	..do	Do.
Henson	P	11	Shrinkage	..do	Acid, metallurgical, lead, zinc, aggregate.
Piasano	P	12	Open pit	Sizing	Metallurgical.
Nye Crowell	P	18	Sublevel	..do	Do.

N Nonproducing as of January 1, 1984. P Producing as of January 1, 1984. T Temporary shutdown.
W Withheld to avoid disclosing company proprietary data.

[1] Number of production years remaining to deplete 1984 demonstrated resources.

[2] Acid feed at approximately 55 pct CaF_2 is sold to Thai Fluorite Processing Co. for their Ban Lard mill.

[3] Production started in late 1984.

ing to capacity, production life, and age of the facilities. Where appropriate, costs have been updated to 1984 U.S. dollars according to local currency factors and individual country inflation indexes, weighted proportionately by the impact of labor, energy, and capital of the fluorspar industry on a countrywide basis.

The total operating cost of a mining project is a combination of direct and indirect costs. Direct operating costs include operating and maintenance labor and supplies supervision, payroll overhead, insurance, local taxation, and utilities. The indirect operating costs include technical and clerical labor, administrative costs, maintenance of facilities, and research.

After production parameters and costs for the development of domestic fluorspar deposits were established, the SAM was used to perform various economic evaluations pertaining to the potential availability of various grades of fluorspar. The SAM system is a comprehensive economic evaluation simulator used to determine the constant-dollar, long-run price at which the primary commodity[5] must be sold to recover all costs of production, including a prespecified discounted-cash-flow rate of return (DCFROR) on investment, less all byproduct revenues. The DCFROR is defined as the rate that makes the present value of all current and future revenues equal to the present value of all current and future costs of production. For this study, constant rates of return on investment of both 0 pct (breakeven) and 15 pct were specified. The rate of 15 pct was considered the minimum sufficient to attract new capital to the industry.

The SAM contains a separate tax records file for each State and country that includes all the relevant tax parameters under which a mining firm would operate. These tax parameters are applied to each mineral deposit under evaluation with the implicit assumption that each deposit represents a separate corporate entity. In reality, properties belonging to the same corporation would have certain tax advantages not assumed for this evaluation. Other items included in the analysis are standard deductibles such as depreciation, depletion, deferred expenses, investment tax credits, and tax loss carryforwards. The SAM also contains a separate file of economic indexes to allow for updating all cost estimates for producing and nonproducing operations and undeveloped deposits.

Prices files are maintained in the SAM for all commodities that will be relevant to the availability analyses, and all commodities recovered in the analyses are considered to be marketable. The byproduct commodity prices used in this study are shown in table 2.

Detailed cash-flow analyses are generated with the SAM system for each preproduction and production year of a mine or deposit beginning with the initial year of analysis (1984). Upon completion of the individual analysis for each deposit, all properties were simultaneously analyzed and aggregated into an availability curve.

The availability of each fluorspar product recoverable from a deposit is presented as a function of the total cost of production associated with that product from each deposit. Availability curves are constructed as aggregations of the total amount of commodity potentially available from each of the evaluated operations, ordered from the deposits having the lowest average total cost per unit of production to those having the highest. The potential availability of each fluorspar product at a price can be seen by comparing an expected long-run, constant-dollar market price with the average total cost values shown on the availability curves. The total recoverable tonnage potentially available at or below this price-cost value can be read directly from the total availability curve. Annual availability curves were also constructed to account for the time lags involved in arriving at the total production potential. These curves are simply the total availability of fluorspar in any given year, based on the development and production schedules assumed for each deposit.

Table 2.—Byproduct prices used in economic evaluations (*7, 16*)

Commodity		*Price, January 1984*
Aggregate, limestone	per mt	$3.75
Barite:		
Domestic	per st	105.00
Ground, white	per st	142.50
Ground OCMA[1]	per st	78.75
Unground OCMA[1]	per st	40.00
Gold	per tr oz	370.89
Lead	per lb	.25
Silver	per tr oz	8.18
Tin	per lb	5.69
Tungsten	per lb	13.10
Zinc	per lb	.49

[1] OCMA: Oil Company Materials Association, European specifications for barite. Ground, minus 325 mesh, minimum 91 pct $BaSO_4$. Unground, 91 pct $BASO_4$.

Certain assumptions are inherent in these curves. First, all deposits will produce at full design capacity throughout the productive life of the deposit, except when it was known that an operation was producing at reduced levels, or was temporarily closed under current depressed market conditions. It was assumed that full capacity would be resumed over the next 1 to 4 yr. Second, each operation will be able to sell all of its output at the determined total cost and obtain at least the minimum specified rate of return. Byproducts are considered to be sold at the prices listed in table 2. Third, all preproduction development of all undeveloped deposits began in January 1984.

FLUORSPAR INDUSTRY

Fluorspar is the commercial name for fluorite, a mineral composed of calcium flouride (CaF_2). It is the principal source of elemental fluorine. Fluorspar is marketed in three major grade classifications including acid, ceramic, and metallurgical. Specifications vary in the amount of contained CaF_2 and impurities. Consumers may have various product specifications, particularly for ceramic and metallurgical grades.

GRADES AND USAGE

Acid-grade fluorspar contains not less than 97 pct CaF_2. User specifications may impose limits on silica, calcium carbonate, sulfide or free sulfur, calcite, beryllium, arsenic, lead, phosphates, and other constituents. Acid-grade fluorspar is consumed primarily in the production of hydrofluoric acid (HF) which can be in the form of gas or liquid. HF has numerous applications in the fluorochemical, aluminum, and uranium industries (*27*).

Two standard forms of ceramic-grade fluorspar are No. 1 Ceramic containing 95 to 96 pct CaF_2, and No. 2 Ceramic, containing 85 to 90 pct CaF_2. A medium grade, commonly 93 to 94 pct CaF_2, is also specified by some consumers. Other limitations may be imposed on silica, calcite, ferric oxide, and sulfides according to a particular customer's specification. Uses for ceramic-grade products include fiberglass insulations, fluxes, flint glass, white or colored opal glasses, enamels, and welding rod coatings (*13*).

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[5] For this evaluation, all fluorspar products were considered to be primary, and thus revenues were proportioned according to the relative value of each product. For example, U.S. metallurgical-grade products sold for $125/mt, which is 73 pct of the price of $171/mt for acid-grade products. Revenues assigned to metallurgical products would be 73 pct of those assigned to acid-grade products. There is further discussion on price proportioning in the Price Proportions section later in this report.

Metallurgical-grade fluorspar traded on the world market contains a minimum of 60 pct CaF_2, and is normally consumed by the steel industry. In the United States, a minimum of 70 pct CaF_2 ("effective pct"), with not over 0.1 pct S, and not over 0.25 pct Pb, is specified (*41*). The effective percentage is calculated by multiplying the silica content by a factor of 2.5 and subtracting that amount from the percentage of CaF_2. Thus, a concentrate with 85 pct CAF_2 and 6 pct SiO_2 would be 70 effective pct $(85 - (6 \times 2.5) = 70)$.

In addition to metallurgical grade, an increasing percentage of the fluorspar used in the steel industry is in the form of briquettes made from flotation concentrates of either acid or ceramic grade. The grades of the briquettes range widely and depend upon consumer preference. High grades (90 pct CaF_2) usually have no additive fluxes, but low grades (25 pct CaF_2) are diluted by other fluxing minerals or scrap ore materials. Briquettes are normally manufactured near consuming centers in order to blend in materials otherwise lost as waste.

U.S. IMPORT DUTIES

The duty on fluorspar imported to the United States is $2.10 per long ton fluorspar assaying more than 97 pct CaF_2 (acid-grade) and 13.5 pct ad valorem for all lower grade concentrates and ores, most of which are metallurgical grades (*27*). The duty favors imports of fluorspar of 97 pct or greater, while the ad valorem charge on lower grade products favors lower priced products, as they have a lower value to charge against.

Fluorspar products from Kenya and Morocco currently have duty free entry into the United States under the Generalized System of Preferences (GSP) for developing nations. Fluorspar consumers importing fluorspar from other nations have made several unsuccessful attempts to obtain repeal of duties on fluorspar, particularly since the U.S. fluorspar industry only produces the equivalent of about 10 pct of domestic consumption. The United States relies on imports for most of its acid- and ceramic-grade, and almost all of its metallurgical-grade needs.

WORLD FLUORSPAR PRICES

Published fluorspar prices for 1984 are listed in table 3. These prices can be used for comparison with the average total cost of production shown on the availability curves located in the section of this report entitled Factors Affecting Availability of Fluorspar. One should keep in mind that these are 1984 published prices, whereas the average total cost represents long-run constant dollars over the life of the operation.

Pricing trends for acid- and metallurgical-grade fluorspar over the years 1979-84 are shown in figure 1. These prices represent yearly published averages and are f.o.b. port of export, except the U.S. producer price that is f.o.b. mill, Illinois. Additional transportation costs are not included, and spot prices were not considered. While it is apparent that U.S. producer prices are the highest on the world market, additional freight costs and duty charges must be added to all foreign concentrates imported to the United States.

Table 3.—Fluorspar grades and 1984 market prices (*8, 16*)

Country and product	CaF_2 grade, pct	Comments	Price, $/mt
China[1]			
Acid, dry basis	97	f.o.b. China	110
Metallurgical	[2]70	..do	55
Mexico:			
Acid, dry basis, filter cake.	+97	Tampico, f.o.b. vessel.	108
Ceramic	94-95	Mexican border, f.o.b. cars.	103
Metallurgical	[2]72.5	Tampico, f.o.b. vessel.	80
Northern Europe:			
Acid, dry bulk	97	f.o.b. N. Europe	120
South Africa, Republic of:			
Acid, dry basis	97	f.o.b. Durban	110
United Kingdom:			
Acid, dry basis	97	Dried, bulk delivered tankers.	147
Metallurgical	[2]70	Ex-U.K. mine	70
United States:			
Acid, dry basis	97	Carload	171
Do.	97	Pellets	170
Ceramic, No. 1	95-96	Calcite and silica variable.	165
Metallurgical	[2]70	Pellets	125

[1] Data supplied by R. Fulton.

[2] Effective percentage rating for metallurgical-grade fluorspar defined as percent CaF_2 minus 2.5 times per

Fluorspar prices peaked in 1981 and 1982 and then dropped significantly as reduced demand and oversupply slowed the market. Prices for Mexican[6] metallurgical-grade fluorspar dropped in 1983 as a result of pressure in 1981 and 1982 from Chinese imports, which were commonly $25/mt[7] below delivered Mexican prices in those years (*30*). In 1982, metallurical-grade fluorspar from China accounted for over 58 pct of imports containing less than 97 pct CaF_2.

Price comparisons for acid-grade fluorspar over the years 1979-84 are shown for selected countries in figure 2. In 1982, European and South African producers took advantage of the Mexican producer prices ($154/mt acid-grade, $123/mt metallurigical-grade) and set spot prices well below Mexico's established prices. Spot prices for acid-grade concentrates ranged as low as $85/mt to $115/mt, and some suppliers were delivering concentrates to gulf port areas for $25/mt to $30/mt below the Mexican producer price at Tampico (*31*). In addition to the advantage of being able to undercut Mexican prices, the Republic of South Africa, Spain, and Italy took advantage of lower freight rates for their exports to the United States and northern European ports. Chinese acid-grade prices, at $110/mt to $115/mt delivered f.o.b. Chinese ports, allowed China to also enter the U.S. market.

By 1983, the worldwide industrial slowdown and oversupply of fluorspar during 1982 caused published acid-grade prices to fall to an average of about $120/mt. Mexico still had its controlled price structure in place, and in the scramble for a share of the shrinking market, spot prices from producers in other countries were commonly lower than the Mexican price of $119.41/mt. Some South African producers, for example, were delivering acid-grade concentrates to gulf ports for less than the prices that Mexican producers were allowed to charge for delivery to the same area (*32*). By 1984, Mexico was eager to regain customers and abandoned its pricing structure. The average reported price for Mexican acid-grade concentrates in 1984 was $108/mt, just under the Euro-

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[6] The Mexican Fluorspar Institute, a Government-sponsored agency, set prices for fluorspar products sold by Mexican producers from 1974 until January 1984.

[7] The Bureau (*27*) reported an average import value (c.i.f.) of Chinese metallurgical-grade fluorspar at $94.36/mt for 1982, while Mexican imports were valued at $116.53/mt, a difference of $22.17/mt.

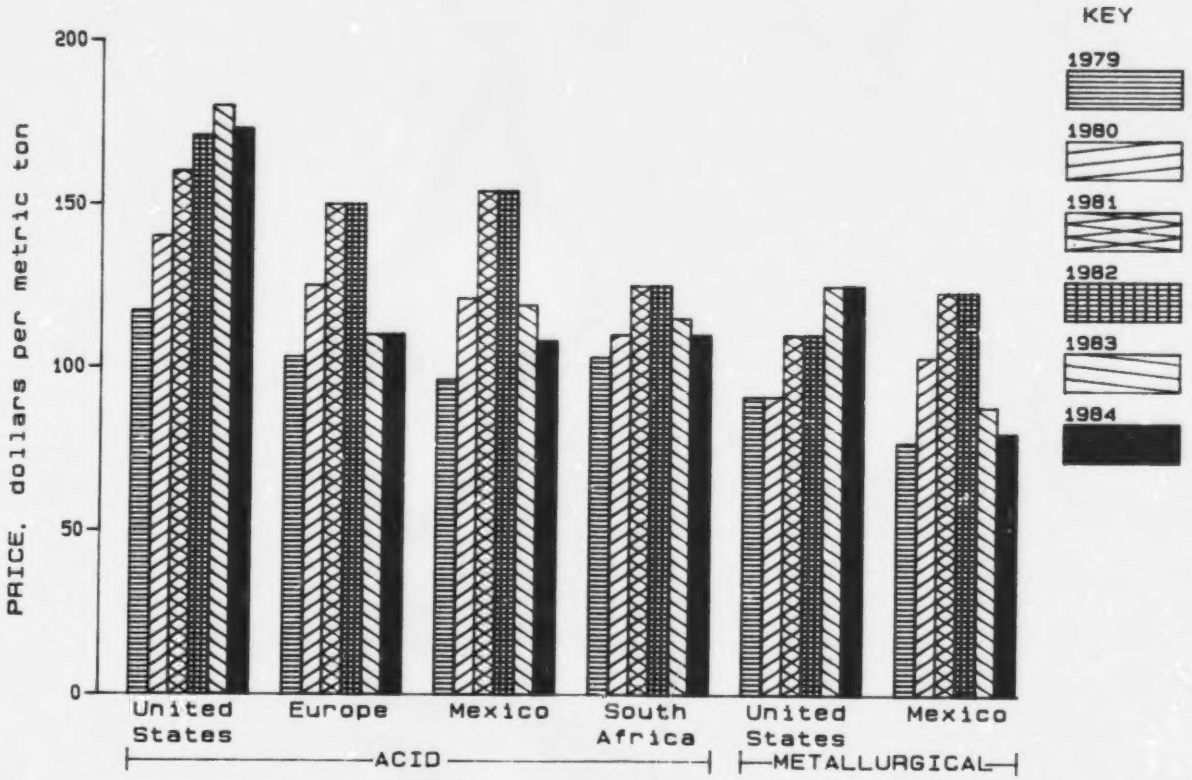

Figure 1.—Acid- and metallurgical-grade fluorspar price comparisons, f.o.b. port.

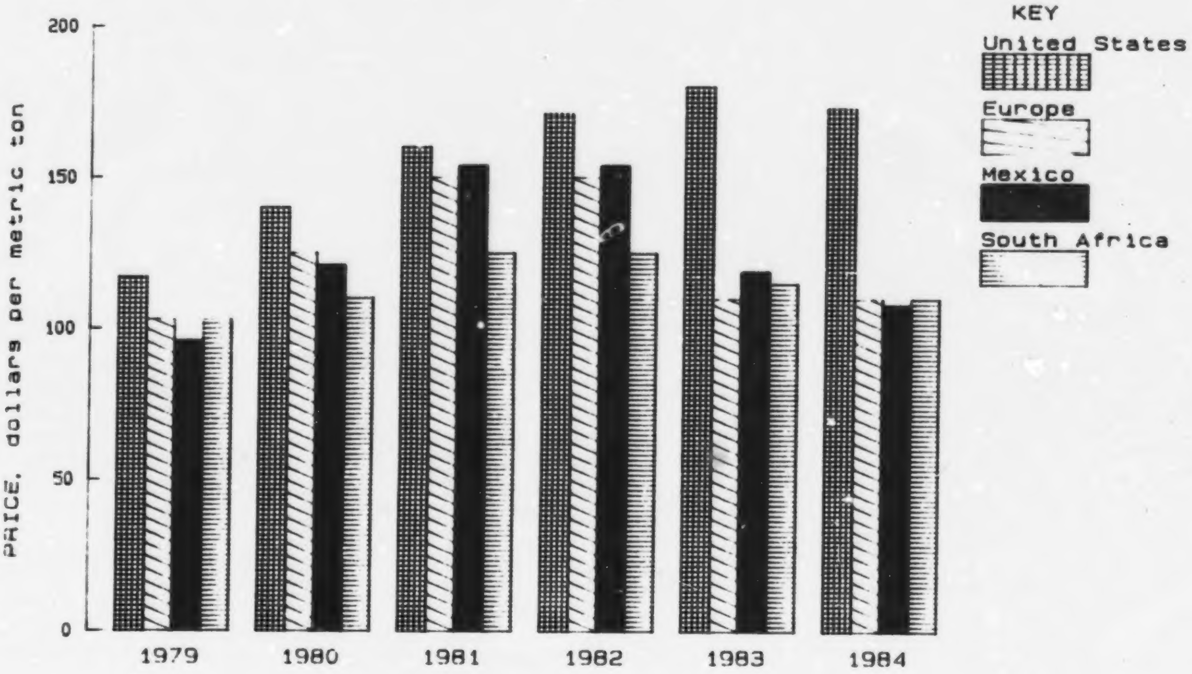

Figure 2.—Acid-grade price comparisons, 1979-84, f.o.b. port.

Table 4.—Number of properties held by ownership type, and availability of fluorspar for export, by country

Country	Number of properties	Ownership			Export fluorspar products
		Private		Government	
		Domestic	Foreign		
China	7	0	0	7	Yes
France	6	1	0	5	No
Germany, Federal Republic of	2	2	0	0	No
Italy	3	2	1	0	Yes
Kenya	1	0	0	1	Yes
Mexico	8	3	[1]5	0	Yes
Morocco	1	0	0	1	Yes
Namibia	1	0	1	0	(2)
South Africa, Republic of	6	1	5	0	Yes
Spain	4	4	0	0	Yes
Thailand	7	7	0	0	Yes
Tunisia	1	1	0	0	No
United Kingdom	3	3	0	0	No[3]
United States	6	6	0	0	No
Total	56	30	12	14	NAp

NAp Not applicable.

[1] Mexico requires 51 pct domestic ownership of all operations. The 5 foreign properties have 40 to 49 pct foreign ownership.

[2] Okorusu deposit in Namibia is undeveloped, plans for production unknown.

[3] Minor exports.

pean and South African published prices of $110/mt to $130/mt.

The lowered prices for fluorspar are taking their toll on the industry, as most operations have cut back production and a number of mines and facilities have been closed or put on temporary care and maintenance status. Higher cost mines nearing depletion have been closed in Mexico, Spain, France, and the United Kingdom. Las Cuevas, the largest producer in Mexico, limited operations to mine development and shipped from its stockpile in 1983, and El Refugio was temporarily closed. The Marico operation in South Africa was placed on care and maintenance in 1982, and several operations in China were stockpiling ore during 1983 for future processing.

OWNERSHIP

Ownership of the 56 operations evaluated has been divided into three categories: private, domestic; private, foreign; and Government controlled. Table 4 lists the ownership type by country according to the number of operations controlled by each group, and shows if fluorspar production is generally available for export. Operations with shared governmental ownership were assumed to be under governmental control. Private ownership was grouped as foreign if there was any foreign party involved. Figure 3 shows the percentage of ownership based on 1984 ore resources. When this illustration is compared with the data in table 4, it is apparent that the distribution of resources is not related to the number of properties per category. On the contrary, while 54 pct of the properties are held by 30 private, domestic companies, 53 pct of the resources are held by 12 private, foreign companies.

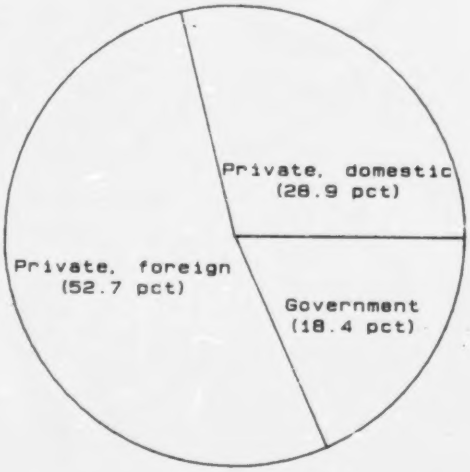

Figure 3.—Demonstrated ore resources (344 million mt), by ownership-type, 1984.

Vertical integration is common in the fluorspar industry; many of the mines are controlled by subsidiaries of large companies that also consume fluorspar products. This true of both private and Government-controlled operations. For example, in the United States Ozark-Mahoning produces acid-grade fluorspar for its parent company, the Penwalt Corp. Mexico requires that 51 pct of Mexican operations be held by nationals; the remaining 49 pct is generally owned by U.S. and Canadian companies. Some of these companies consume fluorspar, others market it. Although operations in France and Tunisia are Government controlled, virtually all production is consumed domestically by the same companies.

Operations in Spain, Thailand, Morocco, Kenya, and the United Kingdom (except Laporte Industries) are not vertically integrated. All but the United Kingdom export the majority of fluorspar produced.

Government operations are affected less by market conditions than their private counterparts, but Government control has different impacts in each country. In France and Tunisia, production is maintained to meet domestic demands; in China and Kenya, production is viewed as a major source of employment, as well as supplying China's domestic requirements.

The labor force at the Kenya fluorspar operation is much larger than needed, but Government laws prohibit a reduction in labor. This effectively makes labor a fixed cost, whereas it is a variable cost for privately owned operations. In China, the Government has taken a new approach and has started basing employee pay upon the units of work completed, resulting in an improvement in worker productivity. Employment has been maintained during the recent slowdown in the fluorspar market, and ore not consumed domestically was being stockpiled in 1982. Several mills were temporarily closed, but employees keep them in top shape, and operations could be resumed in about 2 weeks. Metallurgical grades were stockpiled ready for market, but acid grades were stockpiled as feed and would have to be beneficiated prior to marketing.

COUNTRY OVERVIEWS AND HISTORIC PERSPECTIVE OF FLUORSPAR PRODUCTION

World fluorspar production for 1979-83 is shown in table 5. Annual production of fluorspar from the 13 evaluated countries averaged 67 pct of world production over these years. Annual production from the other MEC's averaged 2 pct, and the remaining 31 pct was produced primarily by the U.S.S.R. and Mongolia, with lesser amounts from other centrally planned economy countries (CPEC's).

The apparent increasing percentage of world production from CPEC's is somewhat misleading. Many of these countries do not report annual production figures to the Bureau of Mines, thus the production numbers may be estimates based upon historical trends and assumed capacities. The assumed growth in these countries does not take into account the overall world decline in fluorspar production, which may have affected the CPEC's as well. The countries in this evaluation that are sheltered from world markets (i.e., they produce primarily for domestic consumption) have not been immune to recession and declines in consumptive industries such as steel and aluminum. They may have suffered less severe cutbacks than exporting countries, but they have suffered cutbacks.

Recent information from Czechoslavakia indicates that the historic reported production and capacity figures for that country are almost double current actual levels. The acid-grade concentrates produced in Czechoslavakia are all targeted for consumption by the U.S.S.R. This information, and exporting information obtained during site visits to other countries, indicates that the U.S.S.R. is not self-sufficient in fluorspar. Operations evaluated in Thailand, Spain, and China also export fluorspar to the U.S.S.R.

Table 5.—Annual production of fluorspar, 1979-82 (27)

	1979	1980	1981	1982	1983[e]
Evaluated countries:[1]					
Production .... 10^3 mt..	3,144	3,335	3,343	2,765	2,707
Pct of total	68.2	69.3	70.0	64.7	62.9
Other MEC's:[2]					
Production .... 10^3 mt..	124	100	103	111	109
Pct of total	2.7	2.1	2.1	2.6	2.5
CPEC's:[3]					
Production .... 10^3 mt..	1,342	1,379	1,381	1,466	1,486
Pct of total	29.1	28.6	28.9	34.3	34.6
World total .... 10^3 mt..	4,611	4,816	4,771	4,275	4,300

[e] Estimated.

Note.—Data may not add to totals shown because of independent rounding.

[1] China, France, Federal Republic of Germany, Italy, Kenya, Mexico, Morocco, Republic of South Africa, Spain, Thailand, Tunisia, United Kingdom, United States.

[2] Argentina, Brazil, Greece, South Korea, Pakistan, Turkey, Uruguay.

[3] Czechoslovakia, German Democratic Republic, North Korea, Mongolia, Romania, U.S.S.R.

AFRICA

The following section includes a brief description of the operations and deposits evaluated on the African continent, in Kenya, Morocco, Namibia, South Africa, and Tunisia. Historical fluorspar production data for each country over the years 1979-83 are compared with world totals. Figure 4 shows the locations of the 10 properties evaluated.

Kenya

Kenya Fluorspar Co. Ltd. (KFC), a wholly owned Kenya Government company, has operated an open pit fluorspar mine and flotation mill since 1979. Located approximately 240 km by air, 400 km by road northeast of Nairobi, the mine lies nearly at the bottom of the Kerio Valley, which is part of the Great Rift Valley.

Table 6 lists the annual fluorspar production for countries evaluated. The decline in Kenyan production since 1981 mirrors world market conditions. The acid-grade filter cake is trucked to a railhead at Kaptagat and then railed to the port of Mombasa on the Indian Ocean. The U.S.S.R. has been the major consumer of the acid-grade concentrates over the last few years.

As a result of the remote location of the mine, and the relative absence of service-oriented dealerships for mining and processing machinery in Kenya, KFC has had to invest heavily in new machinery and spare parts over the last few years. The objective was to build up a 2-yr inventory to avoid the tight restrictions and delays in the allocation of foreign exchange import licenses and the long delays in the supply of items from the United States and Europe.

Morocco

El Hammam fluorspar operation includes an underground shrinkage stope mine, a heavy media plant, and an acid-grade flotation mill located in the foothills of the Moyen Atlas Mountains, 65 km by road from Meknes. The property consists of four concessions owned and operated by Societe Anonyme d' Enterprises Minieres (SAMINE).

The consortium to develop El Hammam was set up in 1971, and initial mine production began in 1974. Full-scale production was reached in 1975. The acid-grade filter cake is trucked to Meknes and then railed to port at Casablanca. All production is exported to various countries.

While production declined in 1982, production levels were expected to return to near normal in 1983. (See table 6). This is because of increased sales to customers, such as the United States, who had previously obtained fluorspar from other countries. In 1983, U.S. acid-grade fluorspar imports from Morocco accounted for 5 pct of total acid-grade imports, up from 3 pct in 1982.

Namibia

The ownership of Okorusu fluorspar deposit is shared by Imkor Pty. Ltd., a subsidiary of Iscor Ltd. and South African Manganese Corp. (Samancor). The undeveloped deposit is located 45 km north of the town of Otjiwarongo, and 12 km northwest of the rail siding of Otjikango.

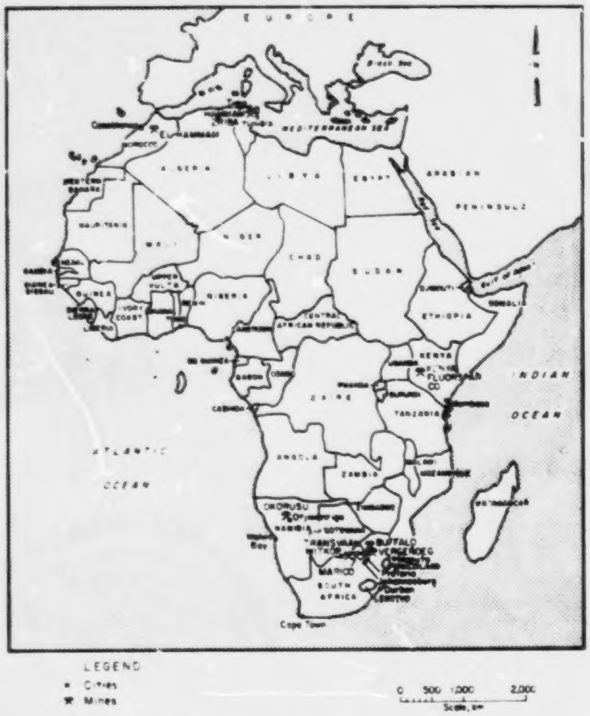
EUROPE
MEDITERRANEAN SEA
MOROCCO
ALGERIA
LIBYA
EGYPT
ARABIAN
PENINSULA
WESTERN SAHARA
MAURITANIA
MALI
NIGER
CHAD
SUDAN
GAMBIA
GUINEA-BISSAU
GUINEA
UPPER VOLTA
IVORY COAST
NIGERIA
DJIBOUTI
SOMALIA
ETHIOPIA
CENTRAL AFRICAN REPUBLIC
GABON
CONGO
CABINDA
ZAIRE
KENYA
FLUORSPAR
TANZANIA
INDIAN
OCEAN
ATLANTIC
OCEAN
ANGOLA
ZAMBIA
MADAGASCAR
OKORUSU
NAMIBIA
TRANSVAAL
BUFFALO
WITKOP
VERGENOEG
MARICO
SOUTH AFRICA
Durban
Cape Town
LEGEND
Cities
Mines
0 500 1,000 2,000
Scale, km

Figure 4.—African fluorspar properties.

Aside from a modest amount of open pit mining and a small adit on the ore outcropping on the Imkor side, there has been no mine development in the area, and no mill has been built. Substantial test drilling, surface trenching, and pitting on both property groups has been performed to establish tonnage and grade values and to provide bulk samples for metallurgical testing. As proposed, this deposit would produce high-grade metallurgical fluorspar, and a 1988 startup date was assumed. Because of the high phosphate content, phosphate-tolerant customers in Europe and North America would be the natural market for the metallurgical-grade filter cake.

Republic of South Africa

The Republic of South Africa's production of fluorspar has become a significant factor in the world total, as shown in table 6. The effect of closing the Marico fluorspar mine in 1982 can be seen in the South African production statistics. Estimated 1983 production was only 52 pct of the high for 1980, but with world production also declining, the South African share of world production has declined by just over 40 pct. Recent production and shipment statistics for the Buffalo Mine, the country's largest producer, also reflect a cutback in line with world market requirements, as shown in table 7.

South African domestic requirements for fluorspar are small, accounting for just about 10 pct of the country's total sales. The local steel industry consumes the bulk of the domestically used fluorspar, about 30,000 to 35,000 mt/yr.

Table 6.—Annual production of fluorspar for evaluated countries and the world, 1979-83 (27)

	1979	1980	1981	1982	1983
China:					
Production .... 10^3 mt..	459	479	479	479	479
Pct of world	10.0	9.9	10.0	11.2	11.2
France:					
Production .... 10^3 mt..	259	258	256	243	240
Pct of world	5.6	5.4	5.4	5.7	5.6
Germany, Federal Republic of:					
Production[1] .... 10^3 mt..	63	78	79	72[e]	73
Pct of world	1.4	1.6	1.6	1.7	1.7
Italy:					
Production .... 10^3 mt..	183	152	164	167	160
Pct of world	4.0	3.2	3.4	3.9	3.7
Kenya:					
Production .... 10^3 mt..	77	93	96	89	[2]59
Pct of world	1.7	1.9	2.0	2.1	1.4
Mexico:					
Production .... 10^3 mt..	875	916	925	631	605
Pct of world	19.0	19.2	19.4	14.8	14.1
Morocco:					
Production .... 10^3 mt..	63	64	67	50	64
Pct of world	1.4	1.3	1.4	1.2	1.5
South Africa, Republic of:					
Production .... 10^3 mt..	451	523	496	331	274
Pct of world	9.7	10.9	10.4	7.7	6.4
Spain:					
Production .... 10^3 mt..	193	245	313	261	187
Pct of world	4.2	5.1	5.4	4.5	4.3
Thailand:					
Production .... 10^3 mt..	235	233	212	241	[3]207
Pct of world	5.1	4.8	4.4	5.6	4.8
Tunisia:					
Production .... 10^3 mt..	34	39	35	33	34
Pct of world	0.7	0.8	0.7	0.8	0.8
United Kingdom:					
Production .... 10^3 mt..	154	171	116	98	200
Pct of world	3.3	3.6	2.4	2.3	4.6
United States:					
Production .... 10^3 mt..	99	84	105	70	55
Pct of world	2.2	1.7	2.2	1.6	1.3
World production .... 10^3 mt..	4,611	4,816	4,771	4,275	4,300

[e] Estimated.
[1] Marketable fluorspar.
[2] Updated information provided by T. Glover.
[3] Updated information provided by G. Kinney.

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Table 7.—Annual production at Buffalo fluorspar mine, 1977-83 (2)

(Thousand metric tons)

Year	Ore treated	Products			
		Acid	Ceramic	Metall.	Total
1977	1,466	101	5	31	137
1978	1,708	118	10	22	150
1979	1,743	144	8	23	175
1980	1,711	172	10	23	205
1981	1,815	182	10	23	215
1982	1,839	156	10	25	191
1983	1,504	115	5	28	148

Domestic ceramic, flux, and HF requirements total from 5,000 to 13,000 mt/yr. South Africa produces HF for its internal requirements only, does not compete in the world market, and has no immediate plans to do so (2). The bulk of South Africa's fluorspar is exported, accounting for the significant share of fluorspar entering world trade.

Loss of production from Marico has also contributed to the decline in U.S. imports from South Africa. U.S. imports of acid-grade fluorspar from South Africa dropped from 39 pct in 1982 to only 29 pct in 1983. While South Africa's shipments to the Far East have also declined, in part as a result of the recent increased availability of Chinese concentrates, distribution remains quite diverse and reflects the similar mileage (nautical miles) from Durban to key market ports: Rotterdam, 7,000; Yokohama, 7,300; and New Orleans, 7,900. The port of Durban has greatly enhanced the country's position in the world fluorspar market, because quick, efficient loading facilities give a large time advantage over the numerous older ports around the world.

As the statistics illustrate, the deep recession of 1982-83 has had a serious impact on the South African fluorspar industry. South African producers have been particularly hard hit because their large, low-grade, open pit operations rely on high-volume production to keep unit costs under control. With this volume absent, much of the needed profit margins have been eliminated at the operating mines (2).

As the recession ends, margins are expected to return to more realistic long-term levels. According to Berger, "South Africa has an excellent reserve position with large mines owned and operated by large, well-financed, multinational companies" (2). It is expected to remain a major supplier of fluorspar to the international fluorspar markets well beyond the year 2000.

Tunisia

Hammam Zriba, located approximately 54 km south of Tunis, was the only fluorspar property evaluated in Tunisia. Nearly all of the fluorspar production in Tunisia comes from Hammam Zriba, with only a small amount of fluorspar concentrates produced as byproducts from Bou Jabeur, a lead-zinc mine southwest of El Kef. The Office Nationale des Mines (ONM) has had favorable results from drilling operations at two other sites, Djebel Guebli, 3 km south of Hammam Zriba, and Hammam Djedidi, about 20 km northeast.

Mineralization at Djebel Guebli occurs at the same stratigraphic horizon as Hammam Zriba, and there is a possibility that the two are continuous. Potential resources for the two could double the amount currently reported by Hammam Zriba. To date, only preliminary exploration has been performed at Djebel Guebli and Hammam Djedidi, and additional work will need to be done prior to making specific plans. The ONM also studied four other sites, but with less success; these rank far below the other prospects.

The mine and mill at Hammam Zriba are owned and operated by Société Minière de Spath Fluor et Barytine (FLUOBAR), which is owned 50 pct by Société Industries Chimiques du Fluor (ICF) and 50 pct directly by the Tunisian Government. ICF is the Tunisian Government's fluorine chemicals company, owned 51 pct by the Government. The balance of 49 pct is divided among the World Bank (Société Financière International), Arab Mining Co. (Jordan), and Banque National de Tunisie. The Government aims to divest its 50-pct direct interest in FLUOBAR and is encouraging ICF to double FLUOBAR's acid-grade output by attracting another investor to provide financing for the expansion.

All of the acid-grade concentrate is consumed by ICF for conversion to aluminum fluoride. ICF trucks the fluorspar from the mill to a railhead at Bou Ficha and then rails it 300 km south to its plant at Gabes. As shown in table 6, Tunisia's production is a small portion of world production.

ASIA

The following section includes a brief discussion of the operations and deposits evaluated in Asia. Historical fluorspar production figures for China and Thailand are discussed (see table 6) and compared with world totals. Figure 5 shows the locations of the seven properties evaluated in China.

China

Six mining districts, with seven fluorspar mills, were chosen in cooperation with the Chinese government for evaluation as the major fluorspar producers. These included the Hong An mining district and mill, Hubei Province; the

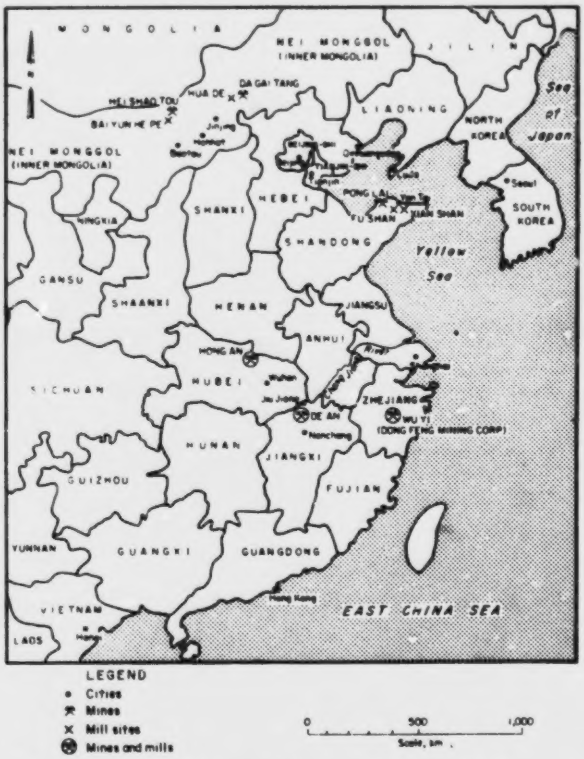
MONGOLIA
NEI MONGGOL (INNER MONGOLIA)
JILIN
DA GAI TANG
HUA DE
HEI SHAO TOU
BAI YUN HE PE
Jining
Hohhot
Baotou
NEI MONGGOL (INNER MONGOLIA)
LIAONING
NORTH KOREA
Sea of Japan
Seoul
SOUTH KOREA
Tianjin
PONG LAI
Yan Tai
FU SHAN
XIAN SHAN
HEBEI
SHANXI
NINGXIA
SHANDONG
Yellow Sea
GANSU
SHAANXI
HENAN
JIANGSU
ANHUI
HONG AN
HUBEI
Wuhan
SICHUAN
Jiu Jiang
DE AN
ZHEJIANG
WU YI (DONG FENG MINING CORP)
Nanchang
HUNAN
JIANGXI
GUIZHOU
FUJIAN
YUNNAN
GUANGXI
GUANGDONG
Hong Kong
EAST CHINA SEA
VIETNAM
LAOS
Hanoi
LEGEND
Cities
Mines
Mill sites
Mines and mills
0
500
1,000
Scale, km

Figure 5.—Fluorspar operations in China.

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Table 8.—Annual U.S. imports from China and the world, 1980-84 (25-27)

	1980	1981	1982	1983	1984
More than 97 pct CaF_2:					
Total U.S. imports .... mt..	577,953	517,882	370,135	349,320	[illegible],027
From China:					
Imports .... mt..	0	0	5,837	5,399	35
Pct of total	0	0	1.6	1.5	0
Not more than 97 pct CaF_2:					
Total U.S. imports .... mt..	273,939	232,011	123,022	61,836	165,341
From China:					
Imports .... mt..	25,054	23,223	71,785	22,109	56,722
Pct of total	10.5	10.0	58.3	35.7	34.3

Hei Shao Tou mining district, which feeds the Bai Yun He Pe mill, and the Da Gai Tang mining district, serving the Hua De mill, Nei Monngol (Inner Mongolia); the De An mining district and mill, Jiangxi Province; the Pong Lai mining district, supplying Fu Shan and Xian Shan mills, Shandong Province; and the Wu Yi mining district and Dong Feng mill, Zhejiang Province. The mines and mills are owned and operated by the local government bureaus as part of the provincial structure of the Ministry of Metallurgical Industries.

China's production of fluorspar represents approximately 11 pct of world production (table 6). About half is used domestically, which reduces the impact on world supply. China has the potential resources and facility capacities to increase production levels when markets improve. The reported production levels have remained constant over a number of years because of the lack of information available from the Chinese Government. According to information obtained during the site visits, mine production was continuing during the worldwide slowdown; however, some of the ore normally processed for export was being stockpiled until world consumption picked up again.

China began exporting metallurgical-grade fluorspar to the United States in 1980; acid-grade products arrived in 1982. As shown in table 8, China has taken a large share of the metallurgical-grade market since 1980. This was a result of markedly lower prices which attracted cost-conscious buyers. In 1981, reported c.i.f. values for Chinese metallurgical-grade fluorspar (containing not more than 97 pct CaF_2) were only \$65.84/mt; this was nearly \$55/mt less than values for Mexican imports, reported at \$120.66/mt (*26*). However, this trend diminished in 1983, as world production and consumption levels dropped and other countries lowered their prices to become more competitive. China did not reduce, but in fact raised prices in 1983.

Although China's share of the U.S. market fell slightly in 1984, the actual tonnage of metallurgical-grade imports increased. The good quality of Chinese products should insure a continuing place in world markets. China is expected to adjust to world pricing strategies soon, and other producers will need to raise prices in the near future if the marginal ones intend to continue to operate.

Table 9.—Annual production of fluorspar for Thailand, 1979-83 (27)

	1979	1980	1981	1982	1983
Production, 10^3 mt:					
Acid-grade	57	60	55	81	[1]47
Metallurgical-grade	178	173	157	160	[1]160
Total	235	233	212	241	[1]207

[e] Estimated.
[1] Updated information provided by G. Kinney.

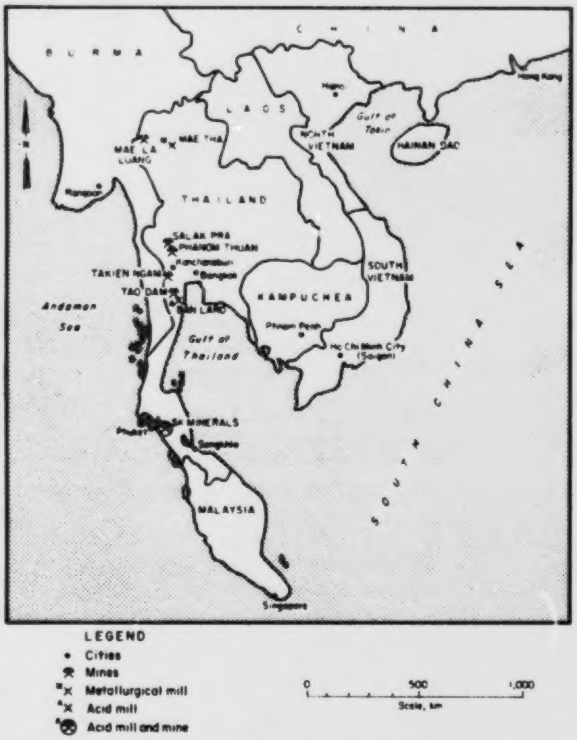

Figure 6.—Fluorspar mines and mills located in Thailand.

Thailand

Fluorspar is produced in Thailand from deposits in three general areas: the northern sector, including Mae Hong Son and Lamphun Provinces; the middle sector of Kanchanaburi, Ratchaburi and Phetchaburi Provinces; and the southern sector in Krabi Province. Figure 6 shows the locations of these properties.

There are two fluorspar mills producing acid-grade concentrates, Krabi International Fluorite Co. (KIF), also known as SK Minerals, and Thai Fluorite Processing Co. (TFP). KIF's mill is immediately adjacent to its ore source. TFP, on the other hand, receives half its ore from its own mine Tao Dam and the other half from about 20 mines located 50 to 200 km away.

Two companies produce most of the metallurgical-grade fluorspar in Thailand. These are United Fluorite Mining Co. (UFM), which has two active mines in Kanchanaburi Province, and Universal Mining Co. (UMC), also with two active mines. UMC also produces metallurgical-grade fluorspar via heavy media separation from old mine dumps in the northern sector at Mae Tha. Dumps in this once-important mining area contain substantial amounts of unrecovered fluorspar.

All of Thailand's fluorspar production is exported. Main destination points are Japan, India, Australia, Republic of Korea, Taiwan, and the U.S.S.R., with small amounts going to the Netherlands and Federal Republic of Germany. China's entry into the world market has affected Thailand, in that much of Japan's trade has recently shifted to China. Thailand has had to cultivate other clients, notably the U.S.S.R., and ties with Australia and India are also improving.

Thailand's share of world production has averaged around 5 pct since 1979 (table 6). As shown in table 9, most of this tonnage (65 pct) has been in the form of metallurgical-grade products. Thailand's output increased in 1982 to 241,000 mt, the highest level since 1979. This coupled with lower world production levels allowed Thailand's share to increase to 5.6 pct. However, due in part to the world oversupply of fluorspar in 1982, production dropped to 207,000 mt in 1983, or a 4.8-pct share.

Thailand's fairly constant production levels over a number of years indicate its reliability as a supplier. Although defined resources should be depleted before 1990, exploration programs have been at a low level. The high number of past and present mines discovered by chance suggests the good possibility of significant resources being outlined through organized exploration. Therefore, the currently low reported resources should not be mistaken to indicate Thailand is "running out of ore." Resources still need to be defined, however, to assure buyers that Thailand will be able to meet future obligations.

EUROPE

The following section includes a brief discussion of the fluorspar properties evaluated in Europe. Operations in the Federal Republic of Germany, France, Italy, Spain, and the United Kingdom are presented. Historic fluorspar production figures for each country over the years 1979-83 are compared with world totals. Figure 7 shows the locations of the 18 properties evaluated.

Federal Republic of Germany

Two companies in the Federal Republic of Germany (FRG) were surveyed, Fluss-und Schwerspatwerke Pforzheim GmbH (FSP), a subsidiary of Bayer AG; and Sachtleben Bergbau GmbH, a wholly owned subsidiary of Metallgesellschaft AG. FSP operates a fluorspar mine called Kaefersteige, and an associated flotation mill. Sachtleben Bergbau operates the Clara fluorspar-barite mine and a flotation mill located about 13 km away. Although mines have been operated in its area of the Black Forest since the 1400's, fluorspar was not discovered in the hanging wall of the Clara barite vein until the 1970's.

As seen in table 6, West Germany's production of fluorspar has slowed since 1982; however, greater decreases in world production levels resulted in a slightly higher percentage share of the world market for 1982 and 1983. Most of the fluorspar concentrates produced in West Germany are consumed domestically, and over half is produced for Bayer's HF plant in Leverkusen.

France

There were five operations producing fluorspar concentrates in France at the time of the site visit in 1983. All are vein deposits, two of which are mined from open pits, three from underground operations. All but the Rossignol Mine are controlled by subsidiaries of Pechiney, a Government-owned chemical and manufacturing complex.

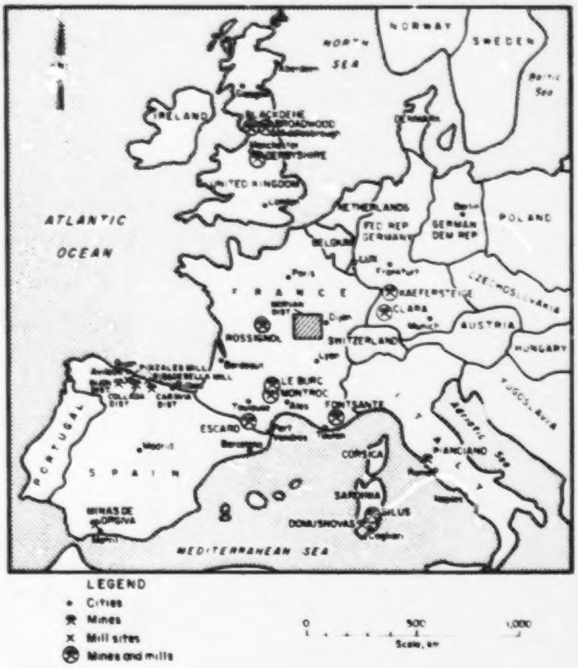
NORTH SEA
NORWAY
SWEDEN
Baltic Sea
IRELAND
BLACKDENE
BROADWOOD
DERBYSHIRE
UNITED KINGDOM
NETHERLANDS
FED REP GERMANY
GERMAN DEM REP
POLAND
ATLANTIC OCEAN
BELGIUM
Paris
Frankfurt
F R A N C E
MORVAN DIST
KAEFERSTEIGE
CLARA
CZECHOSLOVAKIA
Dijon
ROSSIGNOL
Munich
AUSTRIA
SWITZERLAND
HUNGARY
Lyon
LE BURC
MONTROC
Bordeaux
YUGOSLAVIA
FONTSANTE
ESCARO
Madrid
PORTUGAL
S P A I N
CORSICA
PIANCIANO
I T A L Y
Adriatic Sea
SARDINIA
SILIUS
DOMUSNOVAS
MINAS DE ORGIVA
MEDITERRANEAN SEA
LEGEND
Cities
Mines
Mill sites
Mines and mills
0
500
1,000
Scale, km

Figure 7.—European fluorspar operations.

France also has one of the world's largest undeveloped resources located in the Morvan Regional Park. The Morvan is a well-known scenic area, and environmental concerns have slowed development of the estimated 17 million mt of demonstrated resources located in near-surface stratiform deposits (*39*).

Production from vein mines has supplied France for many years, but additional resources will have to be brought into production if the country hopes to maintain its self-sufficiency in fluorspar. The immense resources of the Morvan District could meet this need, and possibly produce enough to allow France to become a major exporter for the world fluorspar market (*4*).

Table 10.—Annual production of fluorspar for France, 1979-83 (27)

	1979	1980	1981	1982	1983
Production, 10^3 mt:					
Acid-grade	157	159	169	161	160
Metallurgical-grade	102	99	87	82	80
Total	259	258	256	243	240

France's production of fluorspar as compared with the world total is shown in table 6. Depletion of several vein operations over the last few years is evident in decreased production levels, particularly for metallurgical grades. (See table 10.) The depressed fluorspar market of the 1980's has allowed France to keep its percentage of world production. Most of France's production is used domestically, with some metallurgical-grade gravel exported, primarily to the steel mills in West Germany. Virtually all acid-grade concentrate produced by the operations used in this evaluation is consumed at the Pechiney HF plant in Ales.

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France has been able to meet its fluorspar needs and is a small net exporter of fluorspar concentrates. The long-reliable vein mines will be nearing depletion by the early 1990's and other resources, such as those of the Morvan District, will need to be developed. Environmental concerns will have to be overcome prior to development of the Morvan deposits.

Italy

Three properties, including two undeveloped deposits, were evaluated in Italy. Mineraria Silius S.p.A. is the operating company, with several vein mines and a flotation plant at Assemini, near Cagliari, Sardinia, jointly owned with Alcoa and Bayer. Silius also controls mining concessions near Domusnovas, Sardinia, where it is considering extracting fluorspar from old iron ore workings. The other proposed operation is the Pianciano deposit located north of Rome, in central Italy, controlled by Southland Mining Co. of Australia.

The majority of the Silius products are exported to locations in the United States and Europe, although two subsidiaries of Mineraria Silius consume about 45 pct of the acid-grade to make aluminum fluoride and synthetic cryolite. Lead byproducts are smelted domestically by SAMIM. Development of the two proposed operations will depend upon a stronger fluorspar market and improved processing techniques for Pianciano ore.

Fluorspar production from Italy is compared with the world total in table 6. Production from the Mineraria Silius operation slowed from the 1979 high in response to the depressed fluorspar market. Acid-grade production levels dipped in 1980 and then returned to normal by 1982. (See table 11). Substantial domestic consumption of acid-grade concentrates provided shelter from the worldwide slowdown; however, metallurgical production has remained slow and ceramic production has ceased. As illustrated in table 6, Italy's share of world production averages between 3 and 4 pct of the total. Over half of Italy's production is exported to the United States, Europe, and the U.S.S.R.

Italy's two undeveloped resources could be brought into production if market conditions warrant an increase in production. Silius could hold the Domusnovas operation out of development until its other mining concessions are depleted, thus utilizing the same flotation mill at Assemini and avoiding the cost of a second mill. This would assure Silius of a long-term ore supply suitable for acid-grade fluorspar concentrates.

The Pianciano deposit will most likely be developed as a source of metallurgical-grade fluorspar. Difficulties in milling this ore preclude the production of acid-grade concentrates at the present time. Improvements in the world economy, the steel industry in particular, would need to occur before this operation will be seriously considered.

Spain

Fluorspar is mined from four districts: Gijon, Collada, and Caravia, located in Asturias Province in northern Spain, and the Orgiva District, located in Granada near the southern coast. There are three major fluorspar companies in Spain, each with a single flotation mill fed by several mines: Fluoruros S.A., Minerales y Productos Derivados S.A. (Minersa), and Minas de Orgiva (Minor). The Pinzales mill is operated by Fluoruros; Minersa operates the Ribadesella mill; and the Orgiva mill was closed by Minor in 1983 because of labor disputes. For this evaluation, it was assumed that Orgiva resumed production in 1985, as there are adequate resources for future production.

Table 11.—Annual production of fluorspar for Italy, 1979-83 (27)

	1979	1980	1981	1982	1983[1]
Production, 10^3 mt:					
Acid-grade	134	125	129	134	130
Metallurgical-grade	42	26	35	33	30
Ceramic-grade	7	1	0	0	0
Total	183	152	164	167	160

[1] Estimated.

Fluorspar production from Spain has tapered downward from the high of 1981, and despite decreases in world production levels, Spain has not maintained its share of world production, dropping from 5.4 to 4.3 pct (table 6). Most of its production is exported to the United States, Western Europe, and the U.S.S.R., with only minor amounts consumed domestically.

The depressed world fluorspar market and the closure at Orgiva has taken its toll on the Spanish fluorspar industry. As of 1983, the other two companies were operating at reduced rates, generally about 80 pct of capacity. Both Fluoruros and Minersa have undertaken drilling programs and have begun development on additional resources. It is estimated that production could remain steady over the next 20 yr with possible increases available, if the market improves.

United Kingdom

Only two companies remain as producers of acid-grade fluorspar in the United Kingdom: Minworth Ltd. and Laporte Minerals. A total of three mills are operating (a fourth mill owned by Dresser is closed, with no plans for future production). Fluorspar is mined in the North and South Pennine ore fields, from which a percentage of the fluorspar ore actually comes from old mine dumps and stope fillings of lead mines that date back to Roman times. Minworth produces a lead concentrate, and Laporte produces aggregate, barite, and lead concentrates in addition to acid-grade fluorspar concentrates.

Fluorspar production from the United Kingdom in 1982 dropped 57 pct from its high in 1980 (table 6), but was expected to increase in 1983 as a result of the 1982 takeover by Minworth of the failing SAMUK and British Steel operations. The United Kingdom fluorspar production rate dropped to a low of 2.3 pct of the world total, but it may exceed 4 pct in 1983 with the resumption of previous production levels at Minworth's operations. Most U.K. production is consumed domestically by ICI's Mond Division in Cheshire and by Laporte's chemical plants in Rotherham.

The takeover of SAMUK and British Steel by Minworth Ltd. breathed new life into the British fluorspar industry. Consolidation of facilities and resources has allowed Minworth to produce fluorspar more efficiently in the North Pennine ore fields. Resources in this area are sufficiently defined to insure production beyond the year 2000.

In addition to its own operations, Laporte Minerals has acquired the Dresser mill and mines, and plans to study resource potential from these properties, though it does not plan to operate the mill. Although resources are poorly defined in the South Pennine ore field, a 5-yr "rule of thumb" resource has been kept for years, and depletion is not anticipated in the near future.

NORTH AMERICA

The following section includes a brief discussion of the fluorspar properties evaluated in North America. Operations in Mexico and the United States are presented, and historic production figures for each country over the years 1979-83 are discussed. Although Canada has not produced fluorspar since the late 1970's, recent interest has been shown in two properties. Information on the sites in Newfoundland and British Columbia was not available at the time site selections were made for this study; therefore, economic evaluations were not performed.

Canada

Minworth Ltd. of the United Kingdom is looking into resuming production at the St. Lawrence fluorspar mines in Newfoundland that were abandoned by Alcan in 1977. Proposed production could begin as early as 1986, and resources are reported at 80 million mt (*14*). The second property, held by Eaglet Mines Ltd., is located near William's Lake in central British Columbia. Approximately 20 million mt of low-grade (11.5 pct CaF_2) ore has been outlined by drilling. The deposit also appears to contain recoverable quantities of silver, molybdenum, lead, and zinc. This deposit could be developed in the late 1980's, with potential markets primarily in Canada and the United States (*40*).

Mexico

Eight mining operations, including 10 mines and 8 flotation mills, were evaluated in Mexico. Figure 8 shows the locations of the properties. Minera San Francisco del Oro S.A. and Zinc de Mexico S.A. produce acid-grade fluorspar concentrates from reprocessed tailings. The operations included represent the majority of fluorspar produced and available for export. Difficult market conditions have plagued the Mexican fluorspar industry since 1982, resulting in the closure of El Refugio mine and mill and severe cutbacks at most of the other operations.

Mexico's fluorspar resources are vast. Although reported in situ reserves are only 17.5 million mt, most of the resources have cutoff grades of 50 to 60 pct CaF_2, which is considerably greater than the average in situ ore grade in most other countries. Mexico currently has sufficient reserves defined to maintain production beyond the year 2000.

Between 1974 and January 1984, the prices for fluorspar exported from Mexico were established by the Mexican Fluorspar Institute. As South Africa, Morocco, and China began supplying the United States with lower priced fluorspar, despite the longer transportation distances, Mexico found itself being priced out of the market.

Mexico's set prices were used as an effective umbrella for other nations wishing to increase their share of the fluorspar market, and they simply underbid the Mexican set price (*32*). Mexican pricing of metallurgical-grade was especially good for the Chinese, enabling them to enter the U.S. market in 1980. China was able to produce inexpensive fluorspar and could afford to greatly undercut Mexico's prices, as well as the fluorspar prices of other nations.

Since eliminating the price structures in 1984, Mexican producers have reduced their fluorspar prices in a bid to regain their major consumer, the United States. Although Mexican producers have the advantage of naturally high grade fluorspar, they have disadvantages including arsenic impurities in some acid-grade concentrates, high-cost vein mines, and older port facilities. In order to stay competitive in coming years, Mexico will need to improve its transportation industries to keep up with improvements being made in other countries.

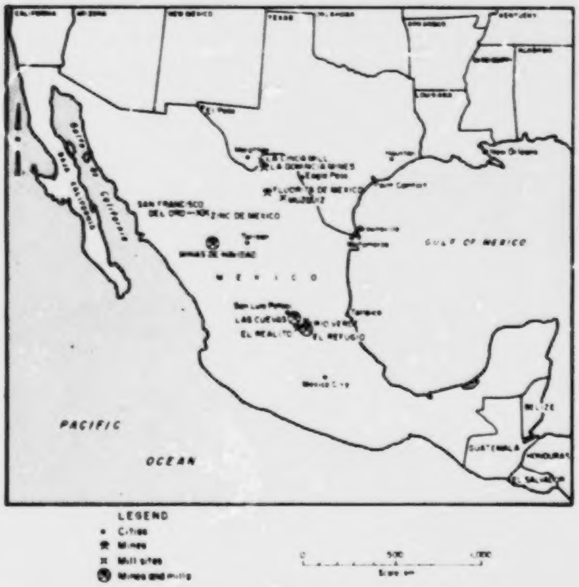

Figure 8.—Fluorspar operations in Mexico.

In 1982, the overall slump in the world steel, aluminum, and chemical industries along with fixed prices caused production to drop significantly. (See table 6.) Mexico's percentage of world production fell from a high of 19.2 pct in 1981 to 14.8 pct for 1982, with even lower levels estimated for 1983. Surplus production from 1982 caused reduced output levels to remain in 1983.

The amount of Mexican fluorspar imported by the United States for domestic consumption is shown in table 12. Mexico is the largest U.S. supplier of fluorspar, and the loss of U.S. consumers to European, African, and Chinese producers resulted in severe cutbacks in production at most operations in 1982-83 and the closure of the Rio Colorado operation, El Refugio. Oversupply and the downturn in major fluorspar consuming industries have slowed plans for expansions, and in fact have caused reductions at most operations. Las Cuevas, the largest producer in Mexico, only shipped concentrates from stockpiled ore in 1983. Although U.S. imports from Mexcio of metallurgical grades decreased in 1983, overall U.S. imports were down even more, and Mexico's share of the U.S. market increased significantly, from a low of 40 pct to over 64 pct. U.S. import tonnages increased from 40,000 mt to 106,000 mt metallurgical-grade fluorspar in 1984, but Mexico's market share dropped slightly.

United States

Ozark-Mahoning owns the only domestic operation currently producing acid-grade fluorspar concentrates. Its Annabell Lee, Barnett, Denton and Henson mines are all

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Table 12.—Annual U.S. imports from Mexico and the world, 19[illegible]-84 (25-27)

	1980	1981	1982	1983	1984
More than 97 pct CaF_2:					
Total U.S. imports ....mt..	577,953	517,882	370,135	349,320	473,027
From Mexico:					
Imports ....mt..	294,997	248,886	133,493	158,832	205,722
Pct of total	51.1	48.1	36.1	45.4	43.5
Not more than 97 pct CaF_2:					
Total U.S. imports ....mt..	273,939	232,011	123,022	61,836	165,341
From Mexico:					
Imports ....mt..	199,467	198,776	48,804	39,727	105,507
Pct of total	83.8	85.7	39.7	64.2	63.8

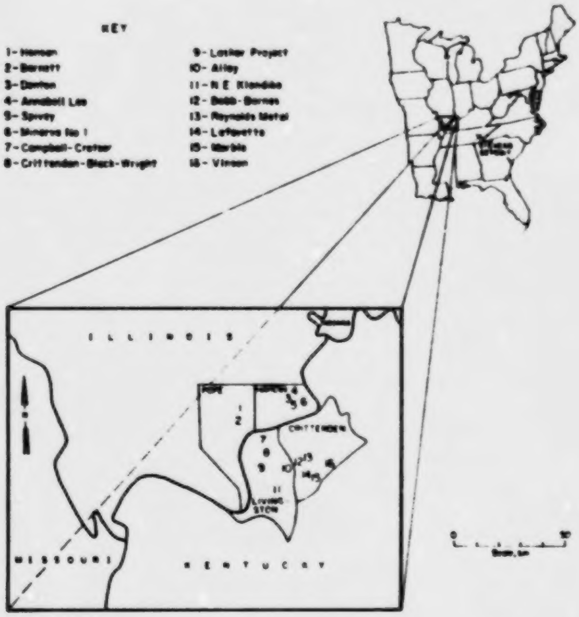
KEY
1- Hansen
2- Barnett
3- Denton
4- Annabell Lee
5- Spivey
6- Minerva No 1
7- Campbell-Crater
8- Crittenden-Black-Wright
9- Lasher Project
10- Alley
11- N E Klondike
12- Babb-Barnes
13- Reynolds Metal
14- Lafayette
15- Marble
16- Vinson
ILLINOIS
MISSOURI
KENTUCKY
POPE
CRITTENDEN
LIVINGSTON
0
Scale, km

Figure 9.—Fluorspar properties in the Eastern United States.

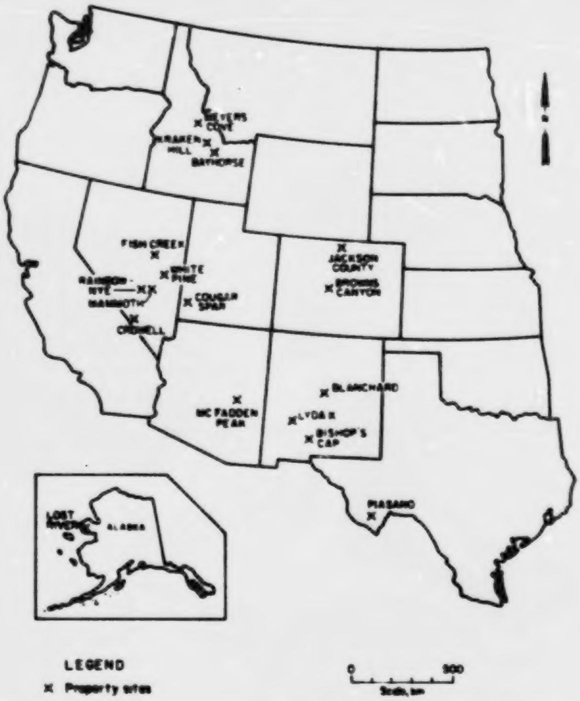
MEYERS COVE
KRAKEN HILL
BAYHORSE
FISH CREEK
WHITE PINE
RAINBOW-NYE
MAMMOTH
COUGAR SPAR
CROWELL
JACKSON COUNTY
BROWNS CANYON
MC FADDEN PEAK
BLANCHARD
LYDA K
BISHOP'S CAP
PIASANO
LOST RIVER
ALASKA
LEGEND
× Property sites
0
500
Scale, km

Figure 10.—Fluorspar properties in the Western United States.

located in southeastern Illinois and feed one mill. The Hastie Trucking and Mining Co. operates relatively small mining ventures near Cave-In-Rock, IL. Its product is sold as metallurgical grade or used to supplement the feed material of the Ozark-Mahoning mill. The Hastie operations were not included in this evaluation, owing to the insignificant fluorspar resources reported.

Two small producers of metallurgical-grade fluorspar are located in Nevada and Texas. J. Irving Crowell, Jr. and Sons operates the Crowell-Daisy mine in Nye County, NV, and sells its sized, run-of-mine ore to a local cement plant. D & F Minerals Co. operates the Piasano mine near Alpine, TX, and sells its run-of-mine ore to a local fluorspar ore buyer. Imported acid-grade concentrates are dried by Inverness Mining at the Minerva mill in Illinois and by the Oglebay-Norton Co. at Brownsville, TX.

A pilot plant operation at Kraken Hill, near Challis, ID, has produced minor quantities of ceramic-grade fluorspar, but its resources were only inferred; therefore, it was not included in the analyses. Kraken Hill neighbors the Bayhorse deposit, which has much larger drill-proven resources but is presently not economically viable. Products from Idaho as well as other Western States face great transportation costs to reach market areas of the Gulf Coast, Los Angeles, or Chicago.

All other domestic operations evaluated were either past producers or undeveloped deposits with no immediate plans for development. For these reasons, and the fact that all had estimated average total costs above domestic producer prices, only the six properties with economic reserves in Illinois, Texas, and Nevada were compared with other world properties.

Locations of the 36 domestic properties originally evaluated are shown in figures 9 and 10. Fluorspar properties located in the eastern half of the United States are shown in figure 9, figure 10 shows those in the Western United States.

While the United States averages less than 2 pct of world production, it is the largest consumer among the MEC's. As illustrated in table 6, the small production percentage for the United States indicates that it must import most of its needs. A small amount of U.S. fluorspar is exported, primarily to Canada. In 1984, 11,100 mt were exported, of which 10,800 mt went to Canada.

In 1984, the United States imported 473,000 mt of fluorspar concentrates containing more than 97 pct CaF_2 (acid-grade). Table 13 illustrates U.S. imports of fluorspar

Table 13.—U.S. imports of fluorspar for consumption, by country, 1981-84 (*26-27*)

Country	1981		1982		1983		1984	
	10^3 mt	pct	10^3 mt	pct	10^3 mt	pct	10^3 mt	pct
CONTAINING MORE THAN 97 PCT CaF_2								
China	0	0	6	1.6	5	1.4	0	0
Denmark	0	0	0	0	4	1.2	0	0
Italy	31	6.0	37	9.9	34	9.7	56	11.8
Mexico	249	48.2	133	35.7	159	45.5	206	43.6
Morocco	0	0	12	3.2	18	5.2	0	0
South Africa, Republic of	213	41.2	146	39.1	103	29.5	177	37.4
Spain	24	4.6	39	10.5	26	7.5	34	7.2
Total	517	100	373	100	349	100	473	100
CONTAINING NOT MORE THAN 97 PCT CaF_2								
China	23	9.9	72	58.5	22	35.5	57	34.3
Mexico	199	85.8	49	39.8	40	64.5	106	63.9
South Africa, Republic of	10	4.3	2	1.6	0	0	3	1.8
Total	232	100	123	100	62	100	165	100

Note.—Data may not add to totals shown because of independent rounding.

by country for 1981-84. Imports dropped considerably after 1981 (517,000 mt), and in 1982 changes in source countries emerged, as Italy, Spain, and Morocco took advantage of reduced freight rates and high price levels set by the Mexican Fluorspar Institute.

Although 1982 European published prices were similar to Mexico's set prices, spot prices from European producers were lower. U.S. imports of acid-grade concentrates from the Republic of South Africa also dropped in 1982. A much larger drop was seen in 1983 as Mexico reduced its prices and regained market shares to the detriment of South Africa. Abandonment of the Mexican pricing structure in 1984 also helped Mexico's position, but neither Mexico nor South Africa has been able to fully regain its share of the U.S. acid-grade market. Italy has continued to improve its position, and Spain has been able to maintain its higher share.

In 1983, imports of fluorspar concentrates containing not more than 97 pct CaF_2 (primarily metallurgical grades) dropped to 27 pct of the 1981 level, from 232,000 mt to only 62,000 mt. This drop reflects the shutdown of a number of U.S. steel mills over the same time period. Although 1984 saw an increase to 166,000 mt (72 pct of the 1981 level), continuing steel mill closures make it unlikely that the metallurgical-grade market will make a full comeback to the highs of the 1970's.

The United States has drastically changed its source countries for lower grade concentrates since 1981, when Chinese imports became a significant factor; China moved from supplying 10 pct of U.S. imports in 1981 to 58.4 pct in 1982. China underbid 1982 metallurgical-grade prices by up to 25 pct ($30/mt) to secure portions of the U.S. market that formerly belonged to Mexico and South Africa. Metallurgical imports from China were down to 35.8 pct in 1983, but remained steady in 1984 at 34.3 pct. Although imports from Mexico dropped in 1982 and 1983, its share of the dwindling U.S. market increased to over 64 pct in 1983. Improvements in the U.S. market resulted in 106,000 mt metallurgical grades being imported in 1984.

The overall decline in consumption of fluorspar can be followed through the Chinese export statistics. China exported 23,000 mt in 1981, accounting for 10 pct of U.S. imports of metallurgical-grade fluorspar, but the 22,000 mt exported from China in 1983 made up nearly 36 pct of U.S. imports. As U.S. consumption picked up in 1984, increased Chinese exports of 57,000 mt represented only 34 pct of the U.S. import total.

The United States is the largest consumer of all grades of fluorspar among the MEC's. However, it presently imports 90 pct of its needs, as only one major producer, Ozark-Mahoning, continues to produce acid-grade concentrates. The current depressed state of the world market has provided lower prices for imports, and the source countries have shifted with changing prices. Major suppliers include Mexico, China, South Africa, Spain, Italy, and Morocco.

Domestic reserves are small, and production covers only about 10 pct of U.S. demands. Aside from the Ozark-Mahoning operations, and a few other small operations selling run-of-mine ore, most domestic resources are contained in mines and deposits where low-grade ores and/or long distances to market areas make them marginal to subeconomic.

GENERAL GEOLOGY

Fluorite occurs in a wide variety of geological environments, which indicates that deposition takes place in a number of different ways. Deposit specific geological information may be found in the appendix B section for each country. Ten different modes of occurrence of fluorspar are described below (*13*):

1. Fissure vein deposits commonly occur along faults or shear zones and are the most readily recognized form of fluorspar occurrence in the world. Although the vein structure may be persistent, the fluorspar mineralization commonly occurs as lenses or ore shoots separated by barren zones. Fissure veins occur in igneous, metamorphic, and sedimentary rocks.

2. Stratiform, manto, or bedded deposits occur as replacements in carbonate rocks. Some beds are replaced adjacent to structural features such as joints and faults. In frequent instances, there is a capping of sandstone, shale, or clay.

3. Replacement deposits in carbonate rocks along the contact with acidic igneous intrusives are another common type of deposit. Deposits do not have to be the result of contact metamorphism, but may be introduced later, following the contact zone as a conduit and replacing the limestone.

4. Stockworks and fillings in shear and breccia zones are another form in which fluorspar occurs. The Buffalo deposit in the Transvaal consists of a network of fluorspar veinlets in sill-like bodies that are inclusions in the granite of the Bushveld complex.

Table 14.—Fluorspar deposits and deposit type[1]

Country	Deposit type
China:	
Da Gai Tang	Fissure vein.
De An District	Replacement.
Hei Shao Tou	Fissure vein.
Hong An District	Do.
Pong Lai Mining District	Do.
Wu Yi District	Do.
France:	
Escaro	Stratiform.
Fontsante	Fissure vein.
Le Burc	Do.
Montroc	Do.
Morvan District	Fissure vein, stratiform.
Rossignol	Fissure vein.
Germany, Federal Republic of:	
Clara	Do.
Kaefersteige	Do.
Italy:	
Domusnovas	Replacement.
Mineraria Silius	Fissure vein.
Pianciano	Lake sediments.
Kenya: Kenya Fluorspar Co. Ltd.	Fissure vein, replacement.
Mexico:	
El Realito (Rio Verde)	Replacement.
El Refugio (Rio Colorado)	Do.
Fluorita De Mexico S.A.	Stratiform.
La Domincia S.A. de C.V.	Replacement.
Las Cuevas	Do.
Minas De Navidad	Fissure vein.
San Francisco del Oro	Gangue mineral.
Zinc de Mexico	Do.
Morocco: El Hammam	Fissure vein.
Namibia: Okorusu	Carbonite and alkalic rock complexes.
South Africa, Republic of:	
Buffalo Fluorspar	Stockworks.
Kruidfontein	Do.
Marico Fluorspar	Replacement.
Transvaal Fluorspar	Do.
Vergenoeg	Stockworks.
Witkop	Replacement.
Spain:	
Fluoruros	Stratiform, fissure vein.
Gijon Area	Do.
Mina Ana	Stratiform.
Minas de Orgiva (Minor)	Do.
Thailand:	
Mae La Luang	Fissure vein.
Mae Tha District	Do.
Phanom Thuan	Replacement.
Salak Pra	Fissure vein.
SK Minerals	Do.
Takien Ngam	Do.
Tao Dam Mine, Thaivat Mining Co.	Do.
Tunisia: Hammam Zriba	Stratiform.
United Kingdom:	
Blackdene Mines	Fissure vein, stratiform, dump material
Broadwood Mines	Fissure vein, stratiform, dump material, stope fill.
Derbyshire Deposits	Stratiform.
United States:	
Annabell Lee	Stratiform, replacement.
Barnett	Fissure vein.
Denton	Stratiform, replacement.
Henson	Fissure vein.
La Piasano	Replacement vein.
Nye Crowell	Do.

---

[1] Table does not include domestic deposits not classified as reserves.

5. Carbonatite and alkalic rock complexes may have fluorspar at their margins. Fluorspar grades are not usually sufficient to be economic, but the Okorusu deposit in Namibia is made up of a number of bodies of fluorspar in limestones, quartzites, and related rocks which have been intruded and metamorphosed by an alkaline igneous rock complex.

6. Residual deposits of fluorspar are formed in clayey and sandy residuum that results from surficial weathering of fluorspar veins and replacement deposits. These deposits may be the sources of metallurgical-grade fluorspar. They include detritial deposits blanketing the apex of veins and the upper portions of the veins themselves that have been deeply weathered to depths of 100 ft or more.

7. Fluorspar may also occur as a major gangue mineral in lead and zinc veins. Two operations in the Parral area of Mexico are treating the tailings of lead-zinc mines to recover fluorspar from previously discarded gangue minerals.

8. Breccia pipes may contain fluorspar in economic quantities.

9. Fillings in open spaces of veins or stratiform deposits may be filled with fluorspar.

10. Fluorspar may occur in unconsolidated clayey and sandy pyroclastic sediments in the beds of former lakes. The Pianciano deposit near Rome, Italy, is an example of this type. Fluorine from igneous sources permeated the lake sediments and is present as finely disseminated crystals.

Deposits containing economic concentrations of fluorspar are located on every continent, but the major producing operations are located in Mexico, Republic of South Africa, China, Spain, Italy, Kenya, Morocco, Thailand, United Kingdom, U.S.S.R., Mongolia, and the United States. Table 14 shows the known deposit type for the reserves included in this evaluation.

WORLD FLUORSPAR RESERVES AND RESOURCES

PRIMARY FLUORSPAR

For this study, cost estimates and analyses were performed on demonstrated tonnages only, which include measured plus indicated resources. Reserves, defined as economically recoverable material at the demonstrated level, total 97 million mt for the properties evaluated. The reserve base (contained fluorspar at the demonstrated level) for all evaluated properties totals 156 million mt. Domestic in situ reserves of 771,000 mt include five operations currently in production plus the Annabell Lee operation, which began production in late 1984; the reserve base totals 33 million mt. Evaluated reserves and resources are listed by country in table 15; a listing by property is given in table 16.

Demonstrated in situ ore resources for the 36 domestic and 50 foreign properties total 555 million mt at an average grade of 28 pct CaF_2. The in situ identified tonnages are defined to include measured plus indicated plus inferred resources that are economic, marginally economic, and subeconomic (*42*). The contained columns for demonstrated and identified resources can be arrived at by multiplying the percentage grade of CaF_2 by the in situ tonnage. The contained value is the equivalent of 100 pct CaF_2.

All foreign resources, including undeveloped deposits, were found to be economic to marginally economic at published January 1984 prices; thus, the recoverable column on tables 15 and 16 are considered reserves. At the highest cost operations, average total costs ranged up to 5 pct above

Table 15.—Fluorspar reserves and resources, by country, 1984

Country and property name	Demonstrated				Identified		
	In situ ore, 10^3 mt	CaF_2 grade, pct	Contained CaF_2, 10^3 mt	Recoverable CaF_2 10^3 mt	In situ ore, 10^3 mt	CaF_2 grade, pct	Contained CaF_2 10^3 mt
China	36,216	63	22,805	17,411	71,927	61	43,916
France	21,130	42	8,809	7,097	31,536	42	13,266
Germany, Federal Republic of	W	W	W	W	W	W	W
Italy	17,851	41	7,280	6,321	36,760	37	13,605
Kenya	5,950	45	2,678	2,261	46,200	41	18,896
Mexico	33,965	64	21,701	17,574	90,688	40	36,598
Morocco	W	W	W	W	W	W	W
Namibia	7,879	50	3,940	2,963	8,209	51	4,178
South Africa, Republic of	167,766	22	37,224	29,508	300,457	25	74,627
Spain	26,512	33	8,758	6,697	52,431	32	16,736
Thailand	3,329	47	1,552	1,139	5,443	50	2,705
Tunisia	W	W	W	W	W	W	W
United Kingdom	6,668	40	2,650	2,077	19,275	37	7,128
United States:							
Reserves[1]	2,072	41	843	771	4,665	24	1,107
Other[2]	211,131	15	32,473	[3]NAp	409,381	13	54,955
Total or average	223,204	15	33,316	771	414,046	14	56,062
Total or average	555,207	28	155,517	96,783	1,099,558	27	294,539

NAp Not applicable. W Withheld to avoid disclosing company proprietary data; included in totals.

[1] Fluorspar reserves (economic) for 6 properties in Illinois, Nevada, and Texas.

[2] Other includes Alaska, Arizona, Colorado, Idaho, Illinois, Kentucky, New Mexico, Nevada, Tennessee, and Utah properties determined to be uneconomical at a breakeven (0-pct) DCFROR.

[3] Recoverable fluorspar (i.e., reserves for this evaluation) not applicable for uneconomic resources.

Table 16.—Fluorspar reserves and resources, by property, 1984

Country and property name	Demonstrated				Identified		
	In situ ore, 10^3 mt	CaF_2 grade, pct	Contained CaF_2, 10^3 mt	Recoverable CaF_2 10^3 mt	In situ ore, 10^3 mt	CaF_2 grade, pct	Contained CaF_2 10^3 mt
China:							
Da Gai Tang Mine	W	W	W	W	W	W	W
De An District	W	W	W	W	W	W	W
Hei Shao Tou Mine	W	W	W	W	W	W	W
Hong An District	W	W	W	W	W	W	W
Pong Lai Mining District	W	W	W	W	W	W	W
Wu Yi District	W	W	W	W	W	W	W
Total or average	36,216	63	22,805	17,411	71,927	61	43,916
France:							
Escaro	W	W	W	W	W	W	W
Fontsante	380	44	167	147	496	44	218
Le Burc	W	W	W	W	W	W	W
Montroc	W	W	W	W	W	W	W
Morvan District	17,000	37	6,205	4,896	25,500	37	9,308
Rossignol	1,500	69	1,036	861	2,040	69	1,410
Total or average	21,130	42	8,809	7,097	31,536	42	13,266
Germany, Federal Republic of:							
Clara	W	W	W	W	W	W	W
Kaefersteige	W	W	W	W	W	W	W
Total or average	W	W	W	W	W	W	W
Italy:							
Domusnovas	W	W	W	W	W	W	W
Mineraria Silius	W	W	W	W	W	W	W
Planciano	7,780	44	3,414	3,017	15,260	34	5,202
Total or average	17,851	41	7,280	6,321	36,760	37	13,605
Kenya: Kenya Fluorspar Co.	5,950	41	2,678	2,261	46,200	41	18,896
Mexico:							
El Realito (Rio Verde)	W	W	W	W	W	W	W
El Refugio (Rio Colo.)	W	W	W	W	W	W	W
Fluorita de Mexico	W	W	W	W	W	W	W
La Domincia	2,015	68	1,368	1,108	3,870	68	2,628
Las Cuevas	14,059	85	11,950	10,255	19,900	85	16,915
Minas de Navidad	638	50	319	196	700	50	350
San Francisco del Oro	5,802	14	835	437	8,630	15	1,251
Zinc de Mexico	2,592	18	454	293	46,246	14	6,474
Total or average	33,965	64	21,701	17,574	90,688	40	36,598
Morocco: El Hamman	W	W	W	W	W	W	W
Namibia: Okorusu	7,879	50	3,940	2,936	8,209	51	4,178
South Africa, Republic of:							
Buffalo Fluorspar	31,623	14	4,427	4,044	45,500	13	5,779
Kruidfontein	W	W	W	W	W	W	W
Marico Fluorspar	28,000	17	4,760	3,539	28,000	17	4,760
Transvaal Fluorspar	27,000	21	5,670	3,529	60,000	20	12,270
Vergenoeg	W	W	W	W	W	W	W
Witkop	28,913	22	6,419	4,366	34,457	22	7,718
Total or average	167,766	22	37,224	29,508	300,457	25	74,627

Table 16.—Fluorspar reserves and resources, by property, 1984—Continued

Country and property name	Demonstrated: In situ ore, 10^3 mt	Demonstrated: CaF_2 grade, pct	Demonstrated: Contained CaF_2, 10^3 mt	Demonstrated: Recoverable CaF_2 10^3 mt	Identified: In situ ore, 10^3 mt	Identified: CaF_2 grade, pct	Identified: Contained CaF_2 10^3 mt
Spain:							
Fluoruros	W	W	W	W	W	W	W
Gijon Area	W	W	W	W	W	W	W
Mina Ana	W	W	W	W	W	W	W
Minas de Orgiva	W	W	W	W	W	W	W
Total or average	26,706	33	8,758	5,697	52,506	32	16,765
Thailand:							
Mae La Luang	413	65	268	198	913	65	593
Mae Tha	700	25	175	70	1,000	25	250
Phanom Thuan	240	55	132	60	400	55	220
Salak Pra	113	50	57	23	280	50	140
SK Minerals	620	40	248	86	1,050	40	420
Takien Ngam	625	65	419	502	1,400	65	910
Thaivat Mining Co.	618	43	266	201	400	43	172
Total or average	3,329	47	1,552	1,139	5,443	50	2,705
Tunisia: Hammam Zriba	W	W	W	W	W	W	W
United Kingdom:							
Blackdene mines	W	W	W	W	W	W	W
Broadwood mines	W	W	W	W	W	W	W
Derbyshire (La Porte)	2,381	25	595	370	7,380	25	1,845
Total or average	6,668	40	2,650	2,077	19,275	37	7,128
United States:							
Illinois, Nevada, Texas[1]	2,072	41	843	771	4,665	24	1,107
Other[2]	221,131	14	32,473	[3]NAp	409,381	13	54,955
Total or average	223,204	15	33,316	771	414,046	14	56,062
Grand total or average	555,207	28	155,517	96,783	1,099,558	27	294,539

NAp Not applicable. W Withheld to avoid disclosing company proprietary, included in totals.

[1] Fluorspar reserves (economic) for evaluated properties.

[2] Other includes Alaska, Arizona, Colorado, Idaho, Illinois, Kentucky, New Mexico, Nevada, Tennessee, and Utah properties determined to be uneconomical at a breakeven (0-pct) DCFROR.

[3] Recoverable fluorspar (i.e., reserves for this evaluation) not applicable for uneconomic resources.

Table 17.—Classification of domestic fluorspar reserves and resources, 1984

Resource classification	Demonstrated: In situ ore, 10^3 mt	Demonstrated: CaF_2 grade, pct	Demonstrated: Contained CaF_2, 10^3 mt	Identified: In situ ore, 10^3 mt	Identified: CaF_2 grade, pct	Identified: Contained CaF_2, 10^3 mt
Reserves (economic):[1]						
Illinois, Nevada, Texas	2,073	40.70	843	4,665	23.74	1,107
Resources (marginal to subeconomical):[2]						
Arizona, Idaho	3,350	40.99	1,373	3,513	41.39	1,454
Kentucky	4,959	31.36	1,555	5,809	31.24	1,815
Nevada	151,856	10.26	15,584	319,980	10.24	32,764
Tennessee, Illinois	27,560	25.21	6,947	41,459	25.31	10,494
Total or average	187,725	13.56	25,459	370,761	12.55	46,527
Other resources:[3]						
Alaska	25,396	16.16	4,104	25,396	16.16	4,104
Colorado	3,912	45.07	1,763	6,309	39.04	2,463
Idaho, Utah	460	32.79	150	875	28.57	250
Nevada	1,414	24.97	353	4,176	23.16	967
New Mexico, Kentucky	1,864	34.55	644	1,864	34.55	644
Total or average	33,406	21.22	7,014	38,620	21.82	8,428
Grand total or average	223,204	14.93	[4]33,316	414,046	13.54	56,062

[1] Reserves defined as economically recoverable material. Actual U.S. reserves of 771,000 mt available at, or below, current market prices (see table 3) at a breakeven (0-pct) DCFROR.

[2] Marginal to subeconomic resources defined as needing a market price greater than the current prices, but less than 1.5 times that price. For example, the long-run average total cost to produce acid grade fluorspar was below $256.50 (1.5 x $171/mt) at a breakeven (0-pct) DCFROR.

[3] Other resources defined as those operations that would need greater than 1.5 times the current market price to cover the long-run average total cost of production.

[4] U.S. reserve base, defined as total contained fluorspar at the demonstrated level.

the respective 1984 market prices. A number of domestic properties evaluated were determined to have average total costs of production above (by at least 10 pct) the 1984 U.S. producer prices of $171/mt acid grade, $165/mt ceramic grade and $125/mt metallurgical grade. These properties are included in the U.S. reserve base but were not included in the analyses of this report.

The domestic operations found to be uneconomic were broken into two categories to better define their status. Those found to be marginally economic to subeconomic (average total costs between 1.1 and 1.5 times 1984 producer prices) would not be able to compete with the large amount of foreign fluorspar available at considerably lower prices. This situation hampers development plans for the majority of domestic fluorspar properties. As shown in table 17, approximately 76 pct of the U.S. reserve base is included in this category, or 25 million mt. The extremely low grades of these deposits and their remoteness from market areas

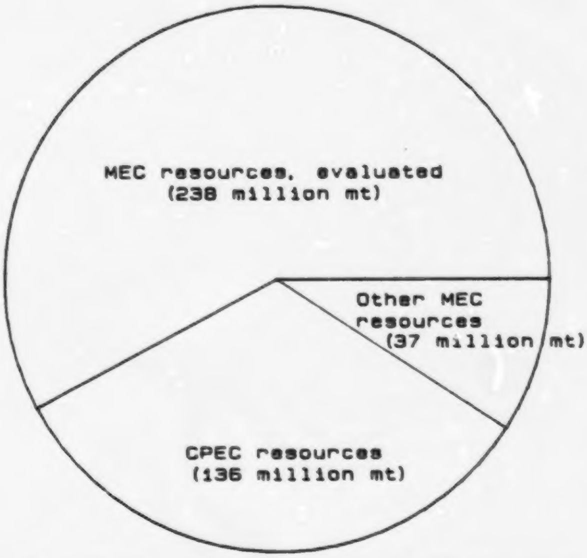

Figure 11.—World fluorspar resources (411 million mt contained CaF_2) for MEC's and CPEC's, showing portion of total resources evaluated.

are the major drawbacks. The "Other Resources" category includes those operations determined to be subeconomic, having an average total cost of production greater than 1.5 times the 1984 domestic fluorspar price at a breakeven DCFROR. "Other Resources" make up 21 pct of the domestic reserve base, with 7 million mt CaF_2.

According to the Bureau of Mines (*29*), fluorspar reserves for MEC's (including China) make up 67 pct of total world reserves; other CPEC's hold 33 pct. Reserves reported by the Bureau can be compared with the identified contained fluorspar data shown in this report. A total of 275 million mt (303 million st) is reported for MEC countries and China; 238 million mt (87 pct) contained fluorspar is shown at the identified level on table 15 for properties evaluated as reserves (excluding U.S. resources). Figure 11 illustrates the MEC and CPEC resources and what portion was evaluated of the total 411 million mt (453 million st) reported by the Bureau (*29*).

Three countries—South Africa, China, and Mexico—hold 67 pct of demonstrated reserves for the 14 countries evaluated. Although South Africa appears to have a tremendous in situ ore resource (168 million mt, 1984), the average grade of 22 pct CaF_2 drops the contained fluorspar to only 37.2 million mt, and reserves are only 29.5 million mt. Mexico and China rank evenly in reserves (517 million mt) and in contained demonstrated resources (522 million mt). Both countries produce from the highest grade deposits in the world, averaging 64 and 63 pct CaF_2, respectively, and both often use reserve cutoff grades between 50 and 60 pct CaF_2. This cutoff grade is higher than the average ore grades of the other evaluated countries, which range from 22 pct CaF_2 in South Africa to 50 pct CaF_2 in Namibia. Mexico and China would have significantly higher resource values if they considered ore with grades as low as the 22 pct CaF_2 in South Africa.

A comparison of demonstrated ore and contained fluorspar is illustrated in figure 12. Note that this figure is broken at 40 million mt, and that South Africa's resources continue to 168 million mt (1984). These figures show the relative amount of ore that must be processed to recover the contained amount of fluorspar. Although 100 pct of the fluorspar resources are not actually recovered (this evaluation averaged 86-pct recovery for all properties), the higher grade operations clearly have the advantage in this area.

All ore from South Africa must be processed through flotation to produce acid-grade concentrates. On the other hand, most of China's and several of Mexico's high-grade operations practice hand-sorting methods to produce metallurgical-grade products. The resulting rejected ore runs around 50 to 60 pct CaF_2, which is then floated to produce acid- and ceramic-grade concentrates. This represents a significant savings in processing costs per metric ton of recovered product. Thailand also benefits from high-grade operations using hand-sorting methods to produce metallurgical-grade products.

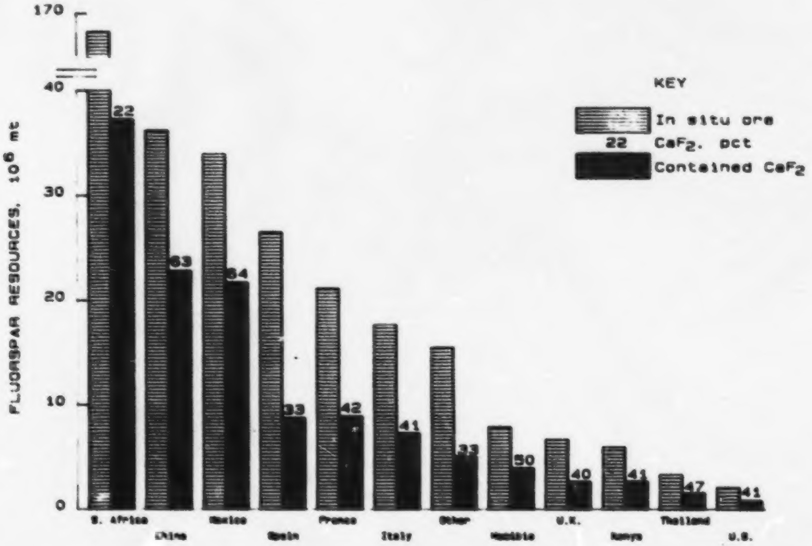

Figure 12.—Comparison of in situ demonstrated ore and contained CaF_2 for 58 properties.

FLUORINE FROM PHOSPHATE

In addition to primary fluorspar resources, fluorine contained in phosphate rock is another important resource. Fluosilicic acid resulting from the processing of phosphate rock can be used in the production of aluminum fluoride, in water fluoridation, and in a number of other chemical applications. Eighteen U.S. plants processing phosphate rock for the production of phosphoric acid and two plants producing hydrofluoric acid sold or used nearly 66,600 mt of byproduct fluosilicic acid in 1983 (*27*).

According to the Bureau of Mines Minerals Availability appraisal of phosphate rock, approximately 1.6 billion mt of potentially recoverable phosphate rock was available at total costs ranging up to $30/mt in January 1981 dollars (*10*). (At costs up to $40/mt, a total of 10.6 billion mt was potentially available.) Based on an assumed average fluorine content of 3 pct and a processing recovery of 35 pct, 16.8 million mt of fluorspar equivalent could potentially be recovered from the 1.6 billion mt of phosphate rock. Although technology exists to recover fluosilicic acid, not all operations find it economically feasible to do so. Therefore, the 16.8 million mt CaF_2 equivalent is a high estimate of the potential resources available.

MINING METHODS

Mining methods vary according to geologic conditions at each of the 56 deposits evaluated around the world. Deep deposits usually require underground techniques, while wide, shallow deposits employ open pit methods. If the ground is unable to support underground mining, open pit methods may be used even though overburden removal might be substantial. In some cases, open pit methods are used until the depth requires moving underground.

Narrow vein mining is often done by shrinkage stoping and open stoping where strong walls occur, while stratiform or bedded deposits use room and pillar patterns. Replacement and fissure vein deposits are mined with shrinkage stoping or cut and fill methods if they are deep, narrow occurrences. They may also be minded by open pit or strip mining techniques where they are near the surface and have competent sidewalls. The replacement and stockwork deposits in South Africa are all mined with open pit methods, as are most of the fissure veins in Thailand. However, replacement deposits in Mexico are extracted by stoping or cut-and-fill methods.

BENEFICIATION

Most fluorspar must be upgraded to meet market requirements, however, high-grade deposits in China, Mexico, and Thailand, and even the United States produce a metallurgical-grade gravel by hand sorting and sizing only. Lower grade ore must be processed by gravity, heavy media separation, or flotation methods to become marketable.

Gravity separation is used for ores with relatively coarse interlocking minerals. Heavy media cone and drum separators are used on finer ores to produce metallurgical gravel or for preconcentrating ore prior to flotation. Heavy media processing can preconcentrate ore as low as 14 pct CaF_2 to yield a flotation feed of 40 pct CaF_2, or more (*13*). Other minerals, such as lead, zinc, and barite concentrate with the fluorspar through preconcentration and can then be recovered through flotation.

Acid and ceramic grades of fluorspar are produced by froth flotation processes. Ore is first crushed and ground to size. Then, if present in recoverable quantities, sulfides are floated off, with the lead first, followed by the zinc. All the easy-floating fluorspar is removed in the next step through a rougher flotation circuit, then sent to the cleaner circuit; the rougher tailing may be further treated in scavenger cells or directly discarded. The middling product may be reground and sent to one or more cleaning circuits to recover more finely interlocked grains of fluorspar and gangue.

Acid-grade fluorspar is normally sold with a moisture content of 8 to 10 pct, because it is easier to load and unload and dust losses are minimized. Some products may be dried in a furnace and either shipped in covered hopper cars or tank trucks or bagged for shipment, depending upon the needs of the customer. Ceramic grades are normally marketed in bags, but dried products may be shipped to large consumers in railcars. Metallurgical-grade fluorspar is usually shipped as lump or gravel products. It is transported in barges, ships, or railcars.

TRANSPORTATION

Fluorspar products are transported to customers by truck, train, barge, and ship. Types of transportation available to producers influence the economic viability of an operation to a certain extent. South Africa must transport its products over long distances from the mines in the Transvaal area to the port of Durban. Fortunately, South Africa has a well-established rail net that serves a large number of mineral producers in the Transvaal area. The port at Durban is highly mechanized and can load and unload ships faster and more efficiently than most ports in the world, allowing shipments to be cost competitive with other less distant producers.

In contrast, Mexico has a less efficient rail and highway network, and the port facilities at Tampico are older; these are disadvantages that can be overcome by short transportation distances (U.S. Gulf Coast). However, the cost competitiveness becomes strained for more distant consumers.

Transportation of products to consumers in the United States takes the form of barge, rail, or truck once they have cleared the port. Truck and rail are much higher than barging costs, and many consumers are located near ports or along major rivers in order to take advantage of lower costs that are provided by proximity to water transportation.

WEIGHTED-AVERAGE TOTAL COST OF PRODUCTION

A weighted-average total cost of fluorspar production at a 0-pct DCFROR was determined for each operation. Total fluorspar revenues were calculated by taking the total property revenues determined by the SAM and subtracting all byproduct revenues. The remaining revenues (total fluorspar revenues) for each operation were then divided by the total tonnage of recoverable acid-, metallurgical-, and/or ceramic-grade fluorspar to provide a weighted-average total cost of fluorspar production, by operation. This evaluation allows for comparisons of fluorspar production costs to be made between selected operations and weighted averages to be compiled for country comparisons.

Figure 13 illustrates the breakdown of the weighted average total cost of production for selected fluorspar properties classified as to whether the primary source of ore is from surface or underground mining techniques. All costs are in terms of metric tons of recoverable fluorspar concentrate and assume a 0-pct DCFROR. The breakeven DCFROR includes the recovery of all investments but no additional profit. Table 18 shows the actual distribution of costs for the 45 selected operations.

Mining costs vary widely among mining methods and deposit types, but make up 20 to 60 pct of total costs for 35 (78 pct) of the 45 properties evaluated. A room-and-pillar mine in a stratiform deposit may cost as low as $6.50/mt to as high as $16/mt of ore mined. However, room-and-pillar costs generally run between 30 and 45 pct of total costs per metric ton of fluorspar concentrate. Economies of scale give an advantage to the large, low-grade open pit mines of South Africa. Stripping ratios (waste to ore) also impact mining costs, particularly for Europe's surface mines. Operations moving large tonnages of waste per metric ton of ore are at an obvious disadvantage, no matter what the final ore grade may be.

Table 18.—Distribution of operating costs per metric ton of fluorspar concentrate produced for selected properties

Percentage	Mining	Milling	Transportation	Miscellaneous
0-10	[1]3	5	14	27
11-20	5	5	8	9
21-30	8	15	14	8
31-40	11	12	8	1
41-50	7	4	0	0
51-60	9	3	0	0
61-70	0	1	1	0
71-80	0	0	0	0
81-90	0	0	0	0
91-100	2	0	0	0
Total[2]	45	45	45	45

[1] Number of properties with costs in given percentage category.

[2] Total does not include 11 operations that had byproduct revenue offsetting a portion of the total cost of fluorspar.

Milling costs are fairly uniform for flotation methods, while costs for heavy media, gravity separation, and screening methods are much lower. Processing costs make up less than 20 pct of the total costs at operations not employing flotation methods, but 20 to 40 pct of the total cost if flotation is utilized.

Transportation costs are usually less than 30 pct of total costs; for 22 (49 pct) of the 45 evaluated operations,

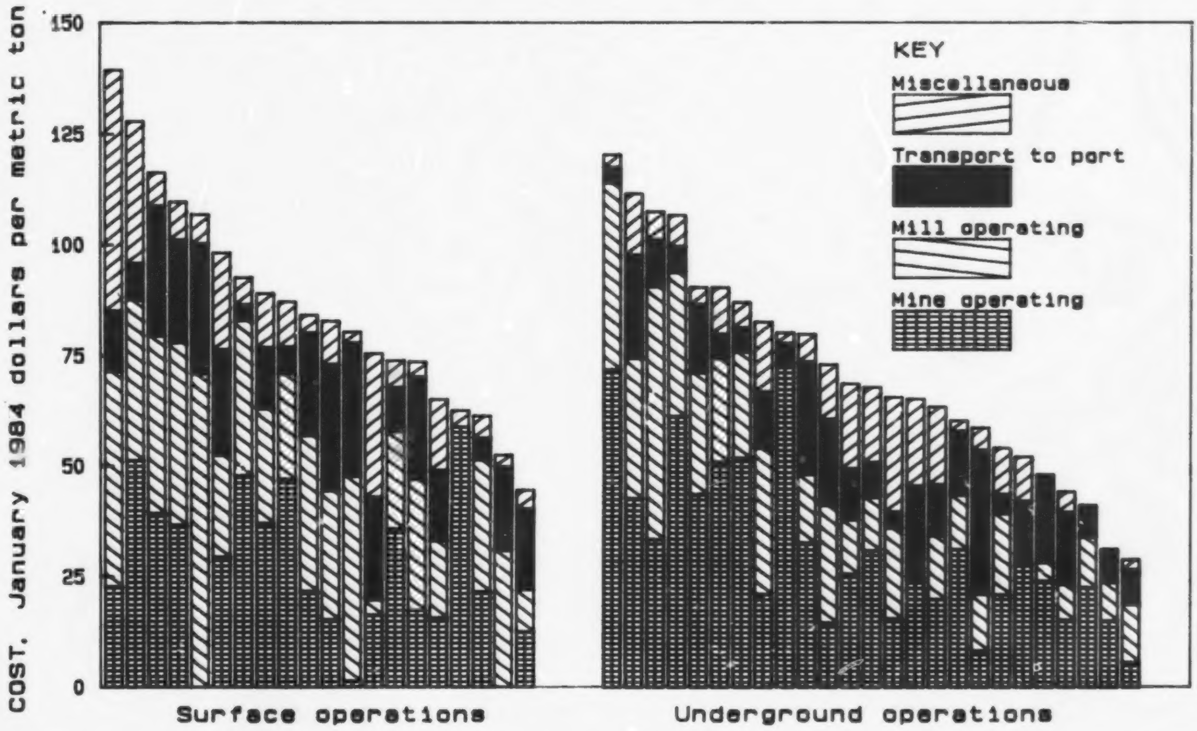

Figure 13.—Fluorspar production costs, weighted average for all grades of fluorspar, 0-pct DCFROR.

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transportation accounted for 20 pct or less. However, transportation costs may be as high as 40 pct for operations utilizing truck and/or rail for haulage over long distances to market or port areas.

Miscellaneous costs represent that portion of the weighted-average total cost not included in mining and milling operating costs or transportation costs. This includes items such as the cost of capital recovery, loan interest payments, taxes, and royalties. For this evaluation, any byproduct credits were deducted from the miscellaneous portion of the total cost.

Miscellaneous costs are greater for undeveloped deposits that must recover large initial capital costs; long-term producers have usually recovered capital costs in previous years. Although the wide variety of costs included in the miscellaneous category make generalizations difficult, miscellaneous costs accounted for less than 10 pct of total costs for 27 (60 pct) of the 45 operations.

COST COMPARISONS, BY COUNTRY

The weighted-average total cost in January 1984 U.S. dollars for selected countries can be compared in figure 14, with a breakdown of these costs given in table 19. The United Kingdom, Italy, and the Federal Republic of Germany are not represented on either figure 14 or table 19 for confidentiality reasons. The United States is shown on the illustration for country comparisons but is not included on the operating cost table in order to protect confidential data. However, the U.S. weighted-average total cost of production (about $90/mt) is lower than the combined mining, milling, and transportation cost per metric ton of fluorspar concentrate. This is because operations in Illinois depend upon byproduct revenues (zinc, aggregate, and some lead) to help with the total cost of production.

In table 19, the cost ranges are average values and do not include costs that were extreme. The values in the total column give an idea of cost ranges, but normally the combina-

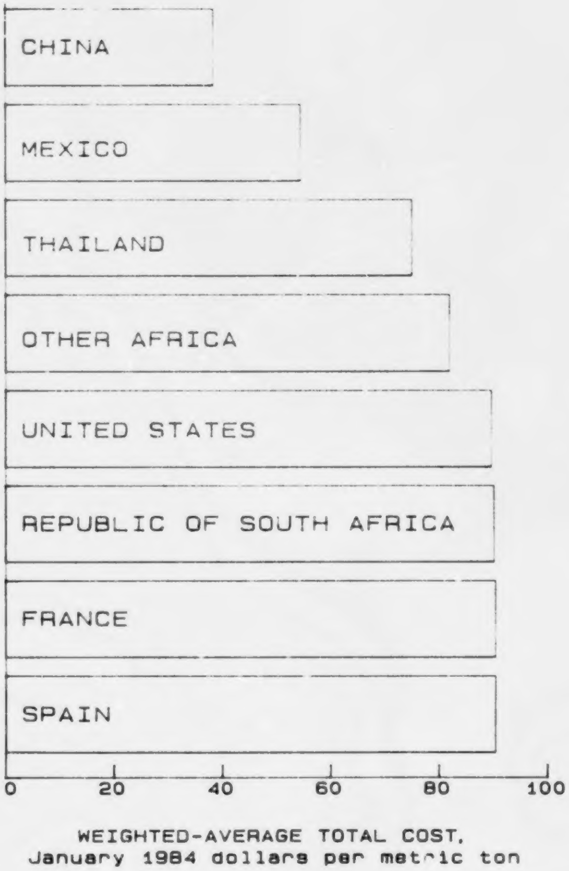

Figure 14.—Breakeven weighted-average total cost of production for all grades of fluorspar, by country.

Table 19.—Average range of operating costs and the percentage of total cost per metric ton of fluorspar concentrate, by country (0-pct DCFROR)

Country		Mining	Milling	Transportation, mill to port	Miscellaneous	Total
China:						
Product cost	$/mt	$10-$25	$10-$15	$7-$20	$1-$8	$28-$68
Average cost	$/mt	$15	$10	$11	$2	$38
Pct of total cost		39	27	29	5	100
France:						
Product cost	$/mt	$30-45	$20-25	$10-$15	$5-$15	$65-100
Average cost	$/mt	$41	$24	$15	$10	$90
Pct of total cost		45	27	17	11	100
Mexico:						
Product cost	$/mt	$20-$30	$12-$18	$10-$25	$6-$19	$48-$92
Average cost	$/mt	$21	$12	$15	$6	$54
Pct of total cost		38	22	29	11	10
Other Africa:						
Product cost	$/mt	$15-$25	$25-$40	$12-$25	$10-$15	$62-$105
Average cost	$/mt	$21	$29	$21	$11	$82
Pct of total cost		25	35	26	14	100
South Africa, Republic of:						
Product cost	$/mt	$20-$40	$30-$40	$20-$30	$3-$10	$73-$120
Average cost	$/mt	$29	$34	$23	$4	$90
Pct of total cost		32	38	25	5	100
Spain:						
Product cost	$/mt	$50-55	$25-$35	$2-$5	$5-$10	$82-$105
Average cost	$/mt	$50	$27	$4	$9	$90
Pct of total cost		55	30	5	10	10
Thailand[1]:						
Product cost	$/mt	$22-$35	NAp	$14-$18	$10-$20	$44-$83
Average cost	$/mt	$31	NAp	$18	$26	$75
Pct of total cost		41	NAp	24	35	100

[1] Costs represent metallurgical-grade production only. Averages for total costs including acid-grade production are above $125/mt at 0-pct DCFROR

Table 20.—Impact of local currency rates of exchange on the weighted-average total cost of production for selected nations

Nation	Actual 1982 total cost, $/mt product	Local currency per U.S. dollar		Projected 1984[1] total cost, $/mt product	Actual 1984 total cost, $/mt product
		1982	1984		
France	101	6.572	7.621	87	90
Mexico	77	54.985	120.094	35	54
Other Africa[2]	84	4.44	5.04	74	82
South Africa, Republic of	88	1.084	1.112	86	90
Spain	111	109.86	143.43	85	90

[1] Projected 1984 total cost calculated by converting actual 1982 cost to local currency, then dividing by 1984 currency per U.S. dollar value. No other factors taken into account (i.e., inflation, changes in capacity or costs, etc.).

[2] Other Africa includes Kenya, Morocco, Namibia, and Tunisia. Currency exchange factors are the average for the four countries.

tion of costs for each operation was not all high or all low. The weighted-average total cost for each country was used to calculate the percentage breakdown of costs, and the percentages may not give the median value of the cost ranges. The average cost per metric ton was determined by the percentage of the weighted-average cost on a country basis, and should be used only for comparison of tendencies between countries, not as the actual average cost for any one operation.

China had the lowest average total cost of production, at $38/mt of fluorspar concentrates. This was directly related to low capital and operating costs associated with the high-grade deposits. China utilizes low cost ($15/mt fluorspar produced) mining methods and hand-sorting methods for recovery of large tonnages of metallurgical gravel. Mexico also benefits from high grade deposits with a small percentage of handsorting for metallurgical products. Mine operating costs average $21/mt of concentrate, however, and the weighted-average total cost of production was $54/mt CaF_2.

Thailand utilizes handsorting for its metallurgical gravel, but mine operating costs average around $31/mt concentrate. Higher milling cost for acid-grade production, and high transportation costs ($18/mt concentrate), together with a 4.5-pct royalty paid to the Government, weighted the costs towards the higher side, at $75/mt CaF_2 concentrate.

The African nations of Kenya, Tunisia, Morocco, and Namibia averaged $82/mt CaF_2 concentrate and fared slightly better than South Africa ($90/mt). This was a direct result of the higher grade ores in the other nations, (40 pct versus 22 pct), which lowers the mine operating cost per metric ton of concentrate. South African mining costs averaged $29/mt concentrate, while other African nations averaged only $21/mt concentrate.

South Africa appears to compete directly with France, Spain, and the United States because of the low-cost open pit mines and economies of scale afforded by their huge operations. These four countries all had weighted average total costs around $90/mt CaF_2 produced. Although France and Spain had higher mining costs than South Africa ($41/mt and $50/mt versus $29/mt), this was compensated for by lower millings costs ($24/mt and $27/mt versus $34/mt), and lower transportation costs ($15/mt and $4/mt versus $23/mt). Spain has the lowest transportation costs (to port areas) of the countries evaluated because all of its operations are located near the coasts. U.S. mining and milling costs were higher than those of the other three countries, but byproduct revenues offset a portion of these costs.

FOREIGN CURRENCY EXCHANGE RATES IMPACT COSTS IN U.S. DOLLAR TERMS

The exchange rates for local currencies play a major role in the results of the cost estimates. While production costs

Currencies in Mexico, Spain, and France saw the greatest devaluation between 1982 and 1984 in relation to the U.S. dollar. While inflation, particularly in Mexico, did cause costs to be higher than the currency exchange rate projected, the actual drop in the weighted-average total cost of production in 1984 was significant: $23/mt (Mexico), $21/mt (Spain), and $11/mt (France).

The drop in costs projected by the exchange rate for South Africa was more than compensated for by inflation, so costs actually increased between 1982 and 1984. On an average basis, the exchange rates of the other African nations of Kenya, Morocco, Namibia, and Tunisia also nearly kept up with inflation and costs declined only $2/mt, despite the projected $10/mt drop.

The relative ranking of countries changed considerably as a result of this devaluation. Ranked in order from lowest cost to highest in 1982, the countries were Mexico, other African nations, Republic of South Africa, France, and Spain. As of 1984, however, devaluation had evened out the costs with Spain and France now able to compete with South Africa; all had weighted-average total costs of $90/mt product.

have been influenced by local inflation between 1982 (year of costs obtained) and 1984 (year of evaluation), the devaluation of local currencies in relation to the U.S. dollar has resulted in an apparent decline in local costs in U.S. dollar terms.

Table 20 shows how currency exchange rates have affected the weighted-average total cost of production for selected evaluated nations. The table lists the exchange rates assumed for this evaluation as well as the 1982 determined weighted-average total cost of production. From these values, a projected 1984 cost (accounting for exchange values only, no inflation) was calculated. The actual determined 1984 weighted-average total cost is shown in the final column.

FACTORS AFFECTING WORLDWIDE FLUORSPAR AVAILABILITY

Many factors contribute to the economic status of a deposit. Capital expenditures vary from deposit to deposit, depending upon the mining and beneficiation methods used as well as the annual capacity. Operating costs are also influenced by mining and beneficiation methods, as well as by economies of scale, ore to waste ratios, and grades of ore. Operations that recover byproducts (such as lead, zinc, and/or barite) have additional revenues to offset production costs compared with those operations that do not recover byproducts. The cost of transportation impacts the total cost of production to various degrees, depending upon the modes of transportation and distance to market or port areas.

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Table 21.—Production estimates for evaluated properties in 1984, and estimated total production capacities for 1984 and 1990, by country (*29*)

(Thousand metric tons)

	1984 production[1]	1984 capacity	1990 capacity[5]
China	505	544	635
France	205	290	544
Germany, Federal Republic of	61	100	100
Italy	150	181	[2]306
Kenya	80	91	91
Mexico	801	1,097	1,360
Morocco	62	73	91
Namibia	NAp	NAp	[3]67
South Africa, Republic of	414	680	907
Spain	167	317	408
Thailand	155	272	91
Tunisia	41	45	45
United Kingdom	159	345	345
United States	54	73	73
Total	2,854	4,108	4,996
Other[4]	NAp	1,687	1,868
Grand total	NAp	5,795	6,864

NAp Not applicable. [5]forecast.

[1] Production figures assumed for this evaluation, 1984. Production rates will differ from actual values as all production rates are assumed, and full capacity is assumed for some operations.

[2] 1990 capacity for Italy assumes development of Pianciano deposit.

[3] Final capacity scheduled for almost 1.1 million mt CaF_2.

[4] Additional capacity for nations not evaluated: Argentina, Brazil, Czechoslovakia, German Democratic Republic, India, North Korea, Republic of Korea, Mongolia, Romania, and U.S.S.R.

Ownership can also affect the availability of fluorspar. Operations controlled by governments may produce fluorspar regardless of world market conditions; they either stockpile excess production, or produce only for domestic consumption. Vertical integration is common, as many of the mining companies are subsidiaries of companies in consumptive industries.

FLUORSPAR PRODUCTION CAPACITY

Production capacities for fluorspar concentrates have been converted from short tons, as listed in Bureau of Mines Bulletin 675, to metric tons, and are shown in table 21 (*29*). Capacities are shown for evaluated countries, with remaining nations listed as "Other" at the end of the table. The 1984 capacity values are installed capacities and include operations known to be shut down, such as Marico in South Africa, Minas de Orgiva in Spain, and El Refugio in Mexico. Production data shown for 1984 are the data used for this evaluation and should not be taken to indicate actual production levels, which may be lower. Most evaluated properties were operating at reduced levels; however, where actual production information was not available, an operation was considered to be producing at or near full capacity.

The capacity values forecast for 1990 include undeveloped deposits and proposed expansions for existing facilities (*29*). For this evaluation, all operations except Okorusu, Namibia, and depleted Thailand operations were assumed to be producing at full capacity by 1990. According to this evaluation, Okorusu would not reach full production capacity until 1994.

Annual production levels were arrived at by assuming (1) current demonstrated reserves will decrease annually with no replacement, (2) presently reduced production rates will return to near capacity levels over the next 2 to 4 yr, (3) all idle operations will be brought back into production in the next 1 to 4 yr, and (4) all undeveloped properties will be developed and commence production in the next 4 to 6 yr.

The nearly 2.9 million mt fluorspar production assumed for this evaluation for 1984 is only 71 pct of the known capacity of 4.1 million mt given for the nations evaluated. As previously mentioned, slow market conditions have resulted in reductions at many facilities, and reduced production levels were used for a number of evaluated operations. Using 1984 as a base year, potential production from the evaluated operations could peak in about 10 yr at 4.5 million mt. However, the capacity forecast for 1990, at just under 5 million mt, would be 10 pct above production levels required for the operations evaluated. Although production appears to decline by the year 2000, proposed production levels for this evaluation (nearly 3 million mt) would be approximately equivalent to the 2.9 million mt estimated for 1984.

Even if the United States produces at capacity, it cannot meet its consumptive needs. In 1983, U.S. apparent consumption was 557,000 mt of fluorspar, of which 411,000 mt (74 pct) was imported. Higher production capacities are not anticipated for the United States, as 98 pct of the domestic fluorspar reserve base is considered marginal to subeconomic. The United States will continue to depend upon other nations, primarily Mexico, China, and South Africa, for its supply of fluorspar.

On the world level, additional capacity would be needed to meet the higher production levels projected by this evaluation, but more than adequate capacity exists to meet current world demands. Although a number of operations are currently producing at greatly reduced levels, the cutbacks are a result of the worldwide slowdown in the industries consuming fluorspar.

TOTAL AVAILABILITY OF FLUORSPAR

Figure 15 shows the total availability and weighted-average total cost of the 56 fluorspar properties. The total in this illustration represents the total cost of production for all products. At a total cost of $75/mt approximately 55 million mt (56 pct) of fluorspar can be produced and all costs of production recovered at a breakeven DCFROR. At $100/mt the recoverable portion increases to 84 pct (82.1 million mt), and at $120/mt, nearly 99 pct of the total 97.5 million mt is available. These costs are not to be compared directly with the market prices for acid, metallurgical, or ceramic grades because they are a weighted average.

PRICE PROPORTIONS

The total cost of production for each fluorspar product was determined by assigning a proportional factor to represent the market price differential for each fluorspar product. Other commodities (byproducts) were given set prices (see table 2), and any resulting revenues (credits) were deducted from the total revenues required to cover all costs at the prespecified DCFROR (0 pct or 15 pct). The remaining revenues were then apportioned between fluorspar products recovered. A market price proportion was assigned on a property by property basis, or on a countrywide basis where pricing was known to be consistent. To avoid the problem of published price ranges, the prices used were supplied by property management in most cases.

The price proportions allow revenues to be divided be-

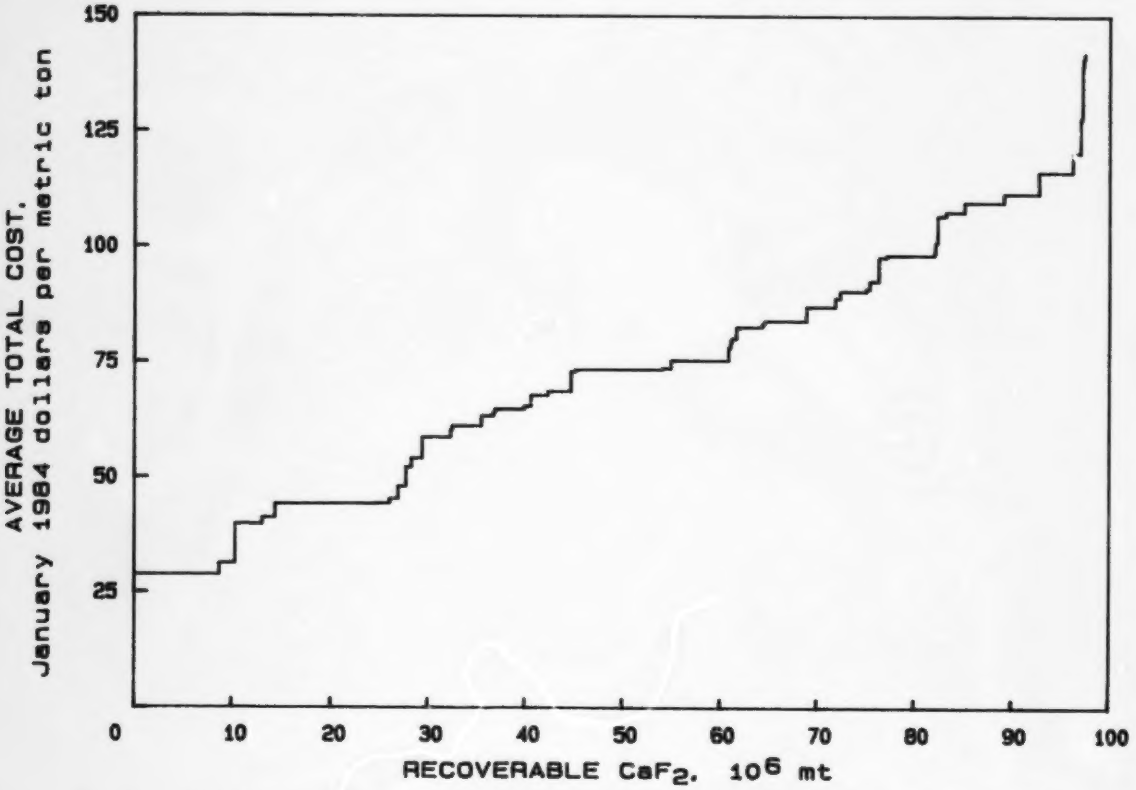

Figure 15.—Weighted-average total cost and availability of fluorspar from 56 properties, 0-pct DCFROR.

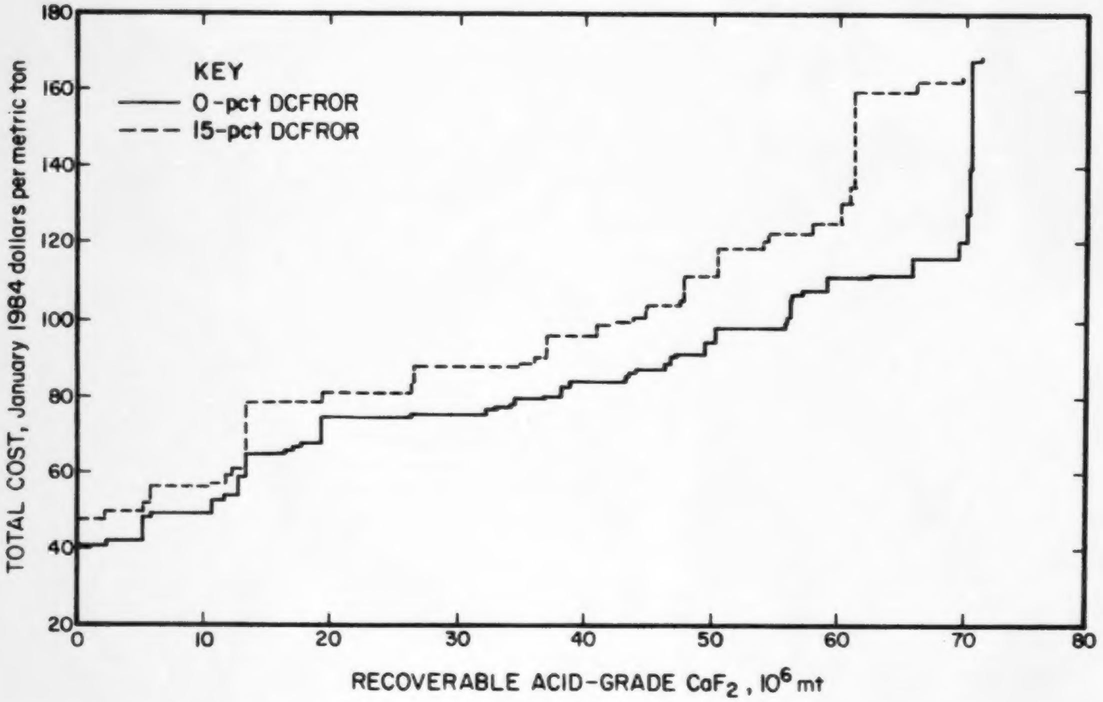

Figure 16.—Cost and total availability of acid-grade fluorspar at 0-pct and 15-pct DCFROR.

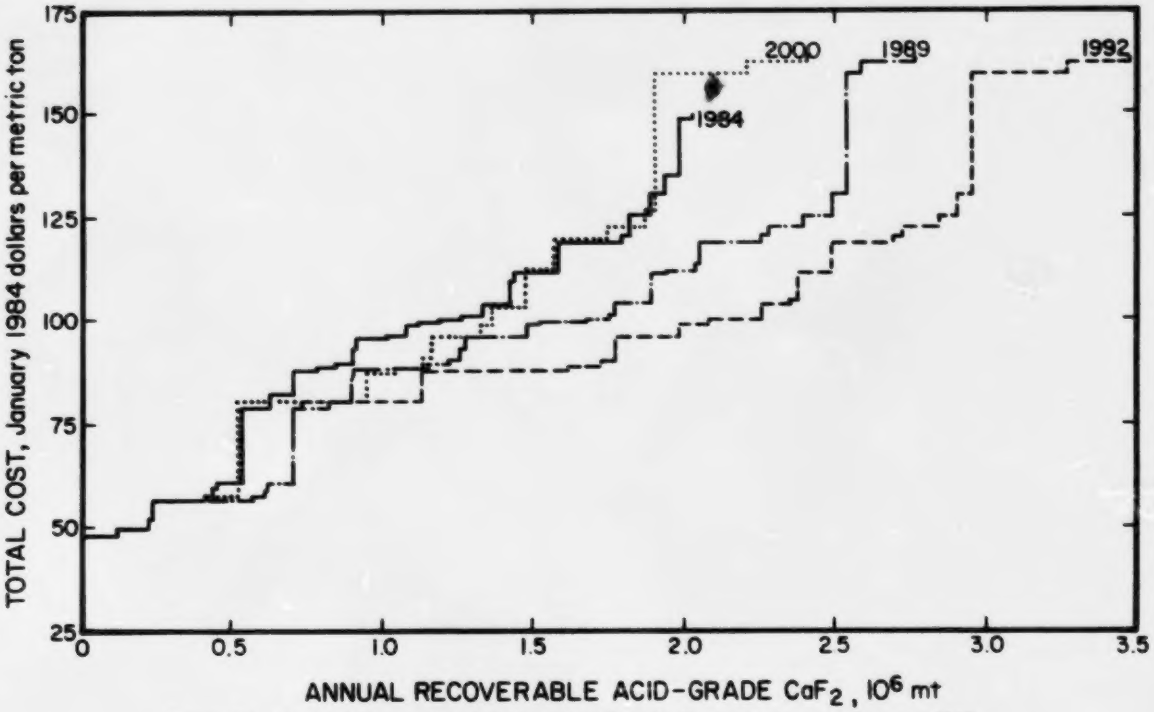

Figure 17.—Cost and annual availability of acid-grade fluorspar through the year 2000.

tween products according to their relative market value, rather than assigning a price for one fluorspar product and determing a price for another. In Mexico, for example, acid-grade concentrates were assigned the factor 1.54 (corresponding to the Mexican producer price of $154/mt for 1981 and 1982), while metallurgical grades were given a factor of 1.23 (price of $123/mt). This resulted in revenue being split such that the metallurgical-grade revenues determined were approximately 80 pct of the acid-grade revenues. Historically, metallurgical prices averaged around 80 pct of acid prices over the years 1979-82; metallurgical prices in 1983 and 1984 prices were listed as 74 pct of acid prices. Overall metallurgical prices ranged from 73 to 82 pct of acid prices for the countries evaluated; China was an exception at 52 pct.

ACID-GRADE FLUORSPAR

Of the 56 fluorspar mines and deposits evaluated, 32 operations recovered a single fluorspar product; 25 of these recovered only acid grades, and 7 recovered only metallurgical grades. The remaining 24 properties were divided as follows: 15 recovered acid and metallurgical grades; 4 recovered acid and ceramic grades; and 5 recovered all three grades. The total availability of acid-grade fluorspar is shown in figure 16. The solid line represents the average total cost required over the life of the operation to meet all costs at a breakeven, or 0-pct. DCFROR. The broken line represents the average total cost of production including a 15-pct DCFROR on invested capital. As illustrated, the costs including the 15-pct DCFROR increase more towards the high end of the curve, where undeveloped operations are more prevalent. As previously explained, established operations have already recovered initial capital expenditures and have fewer costs to cover prior to making the 15-pct DCFROR.

In 1984, the average market price for acid-grade fluorspar was around $110/mt. Approximately 68 pct (48 million mt) of acid-grade fluorspar was potentially available at an average total cost below $110/mt, including a 15-pct DCFROR. (Note that the total costs represent long-run constant 1984 dollar values.)

Annual availability of acid-grade fluorspar is illustrated in figure 17. This illustration should be kept in perspective relative to the assumptions used in the discussion of these curves in the Methodology section. Using 1984 as a base year, production levels increase to a peak of nearly 3.5 million mt in 1992. The values represented for the year 2000 indicated that, although production levels will be declining, they would still be slightly above current rates, as more fluorspar could potentially become available from currently undeveloped or idle operations.

METALLURGICAL-GRADE FLUORSPAR

The total availability of 27 operations proposed to recover metallurgical-grade fluorspar is shown in figure 18. This illustration includes curves representing the 0-pct (breakeven) and 15-pct DCFROR. Market prices in early 1984 were averaging between $60/mt and $80/mt, and almost 92 pct of the evaluated tonnage recovered was potentially available below $75/mt, including a 15-pct DCFROR. About 64 pct (15.4 million mt) could potentially be produced for less than $50/mt. Prices for metallurgical-grade concentrates may be slow to return to the higher levels of the early 1980's because of numerous closures in the steel industry.

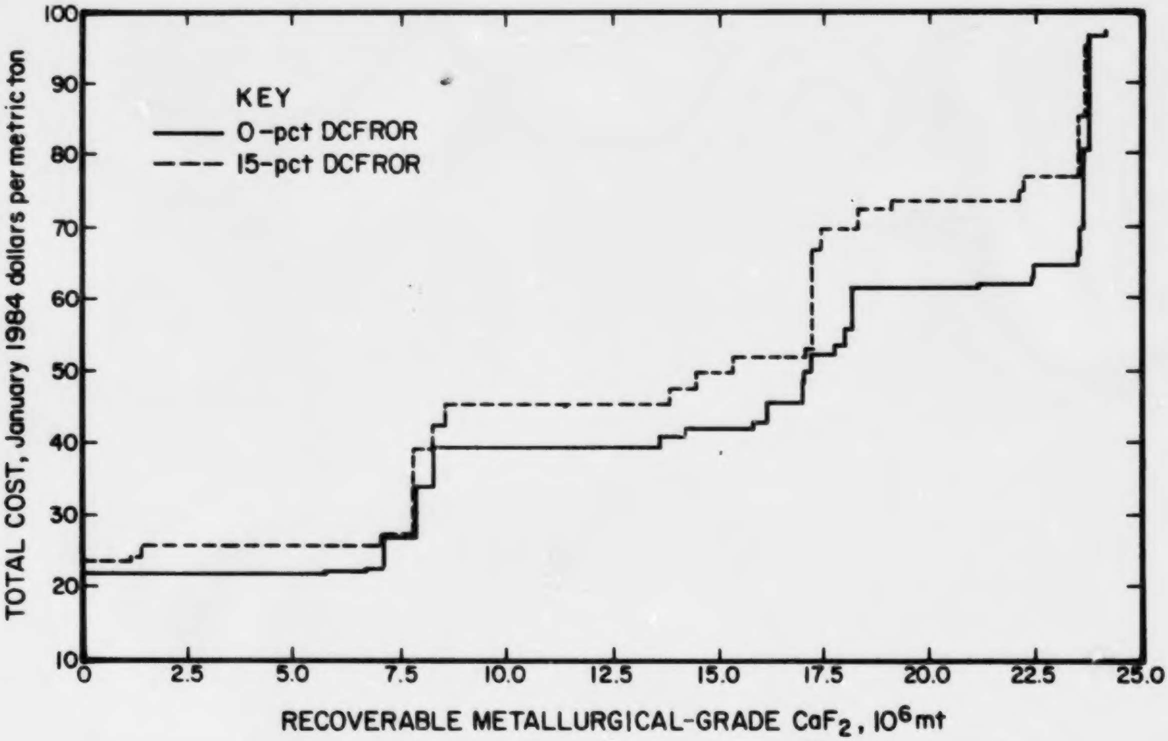

Figure 18.—Cost and total availability of metallurgical-grade fluorspar at 0-pct and 15-pct DCFROR.

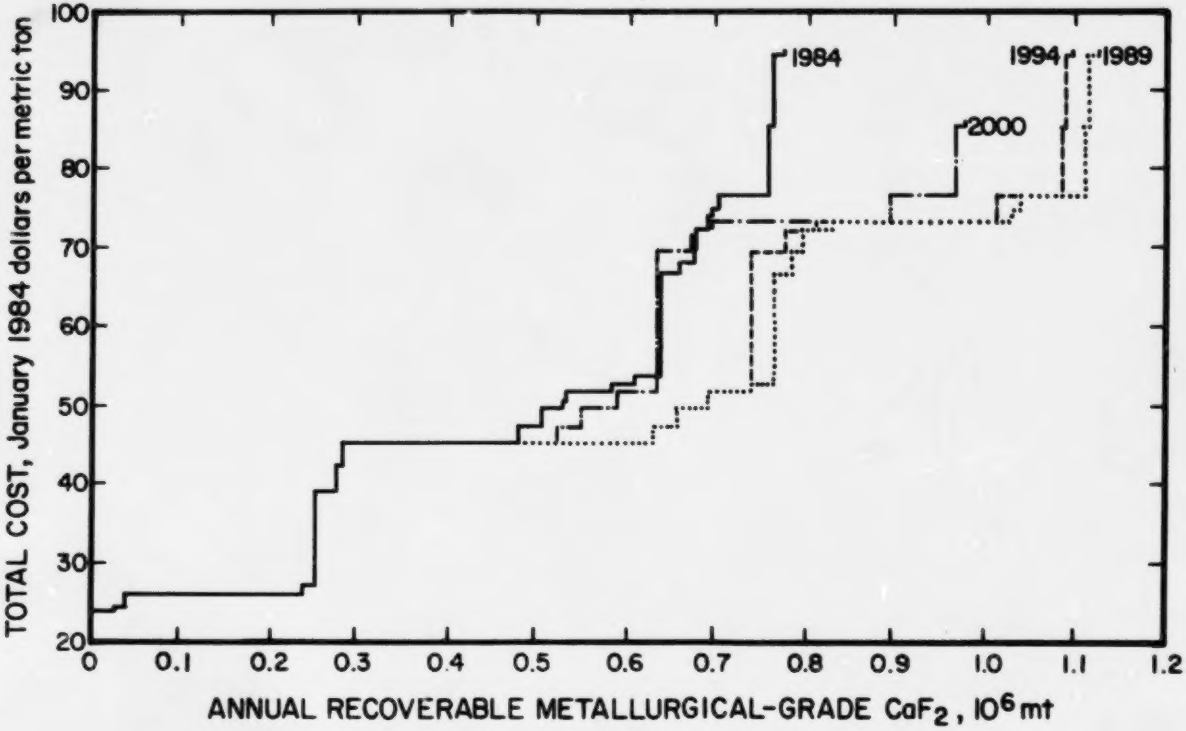

Figure 19.—Cost and annual availability of metallurgical-grade fluorspar through the year 2000.

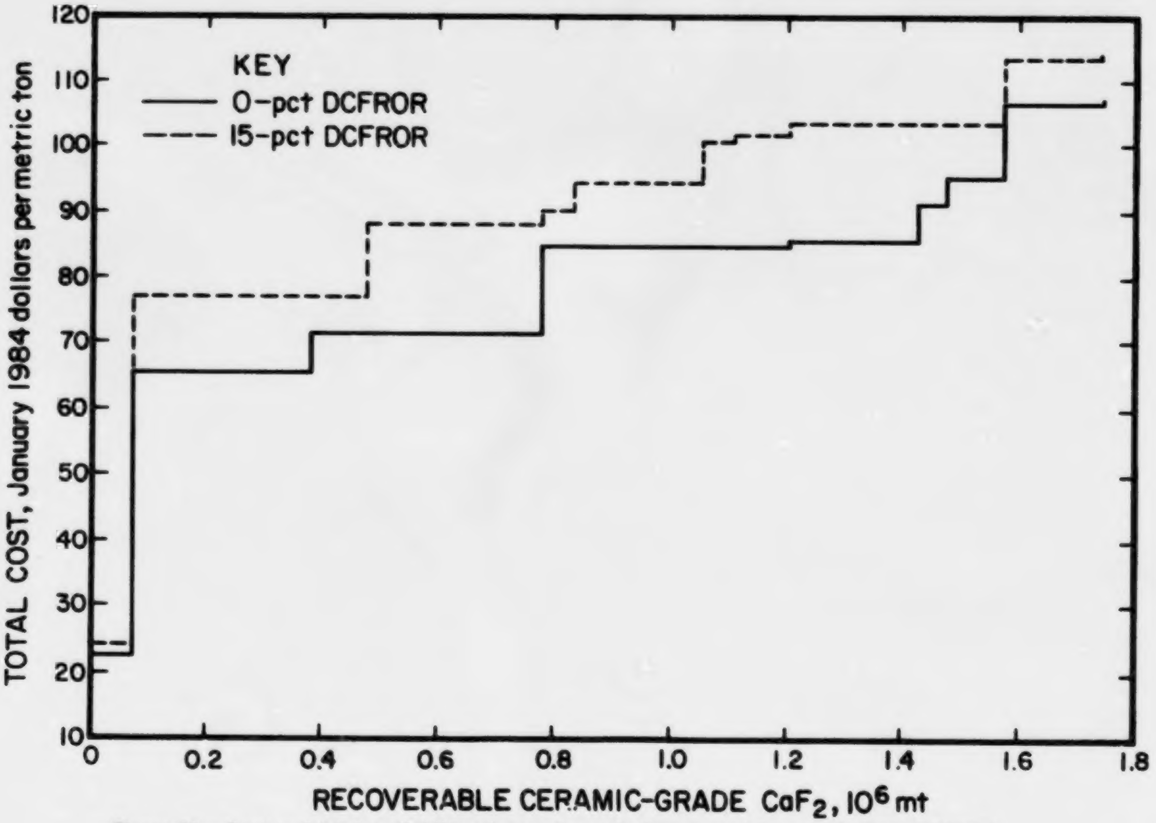

Figure 20.—Cost and total availability of ceramic-grade fluorspar at 0-pct and 15-pct DCFROR.

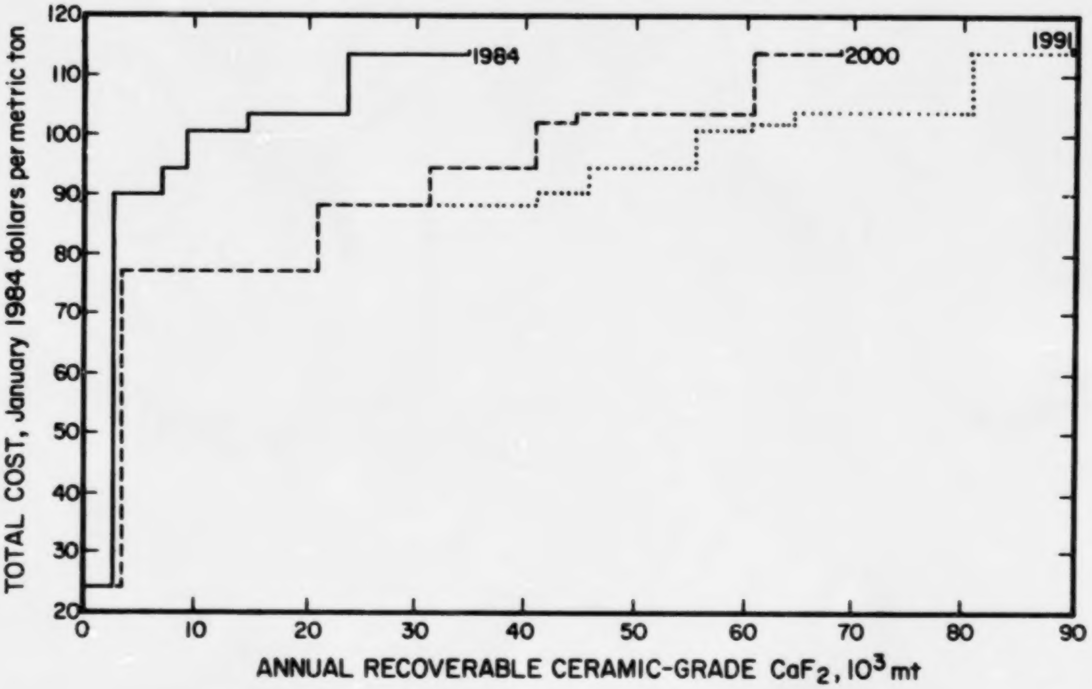

Figure 21.—Cost and annual availability of ceramic-grade fluorspar through the year 2000.

With 1984 as a base year, annual production for metallurgical-grade products peaks at approximately 1.2 million mt in 1989 and then tapers off (fig. 19). Production rates for the year 2000 about equal the current level of 690,000 mt at costs below $70/mt concentrate. This curve should not be taken as an indication of a decline in the availability of metallurgical grades of fluorspar; it simply represents a static view from 1984. The short-term reserves presently defined in Thailand will probably be increased in the future, as formal exploration programs are undertaken. Other resources, particularly in China and Mexico, will undoubtedly be increased as well.

CERAMIC-GRADE FLUORSPAR

The availability of ceramic-grade fluorspar is highly variable, and none of the operations evaluated produce only ceramic-grade products. Ceramic-grade fluorspar is normally produced according to consumer needs and specifications, and because of the closeness in CaF_2 grades, is nearly always produced along with acid-grade concentrates. For this evaluation, at the time of the site visits nine operations that regularly produced ceramic-grade fluorspar were active, expected to continue doing so on a regular basis. Many other acid-grade operations can and do produce small amounts of ceramic grades as consumers request.

Figure 20 shows the total availability of ceramic-grade fluorspar for the properties evaluated. The solid line represents the total cost at a breakeven (0-pct) DCFROR, while the broken line indicates the average total cost including a 15-pct DCFROR. At 15-pct DCFROR, 63 pct (1.1 million mt) of ceramic-grade fluorspar was potentially available at average total costs between $90/mt and $103/mt. However, at 0-pct DCFROR, 86 pct (1.5 million mt) was potentially available at average total costs between $65/mt and $95/mt. The 1984 price for ceramic-grade fluorspar was reported at $103/mt from Mexico and $165/mt in the United States.

Annual availability of ceramic-grade fluorspar is illustrated in figure 21. This figure shows that annual production potentially increases to about 91,000 mt in 1991. The projected production for the year 2000 is well above the current levels with the addition of nonproducing and undeveloped properties. The extreme shifts of these curves are unlikely to occur and represent initiation of development of all undeveloped deposits and resumption of production from closed operations over the next few years.

SUMMARY

Fluorspar prices peaked in 1982 and then dropped significantly as reduced demand and oversupply slowed the market. Consumption dropped drastically in 1982 and 1983, but recovered slightly in 1984. Starting in 1974, the Mexican Fluorspar Institute structured prices for Mexican fluorspar products. In recent years, a number of countries took advantage of the artificially established higher prices and set spot prices well below Mexico's. Some suppliers were delivering concentrates to U.S. gulf port areas for 15 to 20 pct below the Mexican price at Tampico. Eager to regain customers, Mexico abandoned its official pricing structure in 1984. The average reported prices for Mexican concentrates in 1984 were just under those of Europe and South Africa.

The threat of supply interruptions, although inconvenient, would not put many fluorspar consumers at much of a disadvantage because fluorspar is available from a number of different countries. Mexico, South Africa, and China are the three largest producers, with additional sources from other African and European countries. As Mexico found out when it kept its prices high, other nations eagerly filled orders for Mexico's previous customers. It could be assumed that similar arrangements would be made if fluorspar was suddenly not available from any one country. Production capacities may need to be increased to meet additional demands, but since many operations are currently producing at less than capacity, this would not necessarily be a lengthy task.

As of January 1984, world reserves for evaluated fluorspar properties totaled 97 million mt, with a reserve base of 156 million mt. South Africa, China, and Mexico hold 67 pct of the reserves evaluated. Although South Africa appears to have a tremendous in situ ore resource (168 million mt, 1984), the average grade of only 22 pct CaF_2 drops its contained resource to only 37.2 million mt; reserves total 29.5 million mt.

Mexico and China produce from the highest grade deposits in the world, averaging 64 and 63 pct CaF_2, respectively. Both countries often use cutoff grades in reserve calculations that are higher than the average ore grades of the other evaluated countries. Mexico and China would have significantly higher resources values if they considered ore with grades as low as the 22 pct CaF_2 in South Africa.

Mining costs vary greatly, but average 20 to 60 pct of total costs for 35 of the 45 properties evaluated. Milling costs are fairly uniform for flotation methods (20 to 40 pct), with heavy media and gravity separation and screening methods being much lower (less than 20 pct of total costs). Transportation costs are usually under 20 pct of total costs; for 27 of the operations, transportation accounted for 10 pct or less.

China had the lowest average total cost of production at $38/mt of fluorspar concentrates. Mexico ranked second, influenced by its higher mine operating costs, and Thailand was third with high mining costs and royalty fees. Higher grade ores that lower mining costs per metric ton of concentrate resulted in lower cost for the African nations of Kenya, Tunisia, Morocco, and Namibia than for South Africa. The United States, France, and Spain had weighted-average total costs equal to South Africa's at about $90/mt concentrate. What France and Spain gave up to South Africa in mining costs, they made up for in lower milling and transportation costs; most of the U.S. operations have the benefit of zinc and lead revenues to offset production costs.

Local currency exchange rates also impact the overall ranking of fluorspar operations. Although inflation was high in many countries, the strong U.S. dollar negated cost increases in nearly all of the evaluated countries. Devaluation of local currencies in relation to the U.S. dollar had the greatest impact on operations in Mexico, where the weighted-average total cost of production decreased by $23/mt fluorspar product between 1982 and 1984. Devaluation in Spain and France brought their normally higher cost operations down to levels competitive with South Africa.

Of the 56 fluorspar mines and deposits evaluated, 49 recovered acid-grade concentrates, 27 recovered metallurgical grades, and 9 recovered ceramic grades. At a 15-pct DCFROR, approximately 68 pct of acid-grade fluorspar is potentially available below $110/mt, the average 1984 market price. Lower market demand for metallurgical-grade concentrates has lowered world market prices from a high of $123/mt in 1982 and 1983, to between $60/mt and $80/mt in 1984; about 92 pct of the metallurgical-grade fluorspar was determined to be available below $75/mt. Potentially 63 pct of ceramic-grade fluorspar was available at average total costs between $90/mt and $103/mt.

Current productions levels and proposed levels for this evaluation are well below capacity for the nations evaluated. Using 1984 as a base year, potential production from evaluated operations could peak in 1994 at about 4.5 million mt. The capacity forecast for 1990 is over 5.4 million mt. Although production would be declining by the year 2000, productions levels of nearly 3 million mt would be only slightly above the level estimated for 1984.

Most operations are producing at greatly reduced levels as a result of the worldwide slowdown in the industries consuming fluorspar, principally steel and aluminum production and chemical manufacturing. Althouh the aluminum and chemical (primarily HF) industries are showing signs of recovery, fluorspar's position in the steel industry's future does not look promising. The steel industry has been slow to recover, and producers are consuming less and less fluorspar per metric ton of steel. If these trends continue, the fluorspar industry will need to find alternative consumers for its products currently targeted for metallurgical consumption. In addition, the industry needs to improve and expand its markets for higher grades of fluorspar if higher production levels and attractive earnings are to be achieved.

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APPENDIX A.—FLUORSPAR PROPERTIES

Table A-1.—Ownership of fluorspar properties

China:	
Da Gai Tang mines, Hua De mill	Hua De District Economic Commission, CMIEC.
De An District	Jiangxi Provincial Metallurgical Corp.
Hei Shao Tou mine, Bai Yun He Pe mill	Inner Mongolia Branch CMIEC.
Hong An District	Hubei Branch Ministry of Metallurgical Industries.
Pong Lai mines, Fu Shan mill	Yan Tai Prefecture Metallurgical Bureau.
Pong Lai mines, Xian Shan mill	Do.
Wu Yi District	Dong Feng Mining Co.
France:	
Escaro	Denain Anzin Mineraux COMIFLUOR (Pechiney).
Fontsante	Societe D'Enterprises, Carrieres et Minas de L'Esterel (SECME) (Pechiney).
Le Burc	SOGEREM (Pechiney).
Montroc	Do.
Morvan District	Pechiney.
Rossignol	Societe Industrielle du Centre, S.A. (SIC).
Germany, Federal Republic of:	
Clara	Sachtleben Bergbau GmbH (Metallgesellscaft AG)
Kaefersteige	Flus-und Schwerspatwerke Pforzheim GmbH (Bayer AG).
Italy:	
Domusnovas	Mineraria Silius S.p.A.
Mineraria Silius	Do.
Pianciano	Soricom, S.p.A. (Southland Mining Co.).
Kenya: Kenya Flurospar Co. Ltd.	Government of Kenya.
Mexico:	
El Realito (Rio Verde)	Penoles S.A. de C.V., IMC Corp. (40 pct).
El Refugio (Rio Colorado)	Penoles S.A. de C.V., Allied Chemicals, (40 pct.)
Fluorita De Mexico S.A.	IMC de Mexico, IMC Corp. (49 pct)
La Domincia S.A. de C.V.	La Domincia S.A. de C.V., Du Pont (49 pct)
Las Cuevas	Las Cuevas S.A., Noranda (49 pct)
Minas De Navidad	Minerales y Productos Metalurgicos S.A.
San Fransisco del Oro	Minera San Francisco del Oro S.A. de C.V.
Zinc de Mexico S.A.	Industrial Minera Mexico S.A.
Morocco: El Hammam	SAMINE; Ominium Nord African (66.7 pct), BRPM, Moroccan Government (33.3 pct).
Namibia: Okorusu	Imkor (Pty.) Ltd., Samancor.
South Africa, Republic of:	
Buffalo Fluorspar	Transvaal Mining & Finance Co.
Kruidfontein	Southern Sphere Mining & Development Co. (Pty) Ltd. (Utah International).
Marico Fluorspar	Transvaal Land and Investment Co. Ltd.
Transvaal Fluorspar	Samancor Management Services.
Vergenoeg	Vergenoeg Mining (Pty.) Co. (Bayer).
Witkop	Phelps Dodge Mining Ltd.
Spain:	
Fluoruros	Worker's Cooperative.
Gijon Area	Minerales y Productos Derivados S.A. (Minersa).
Mina Ana, Torre mill	Do.
Minas de Orgiva (Minor)	S.M.M. Penarroya-Espana, Minas De Almagrera.
Thailand:	
Ban Lard mill	Thai Fluorite Processing Co. Ltd. (TFP).
Mae La Luang	Universal Mining Co.
Mae Tha District	Do.
Phanom Thuan District	Phanom Thuan Mining Co. (Universal)
Salak Pra	United Fluorite Co. Ltd.
SK Minerals	SK Minerals (Krabi International Fluorite Co. Ltd.)
Takien Ngam	United Fluorite Co. Ltd.
Thao Dam Mine	Thaivat Mining Co. Ltd. (affiliated with TFP).
Tunisia: Hammam Zriba	Societe Miniere de Spath Fluor et Barytine (FLUOBAR); Societe des Industries Chimiques du Fluor (ICF) (50 pct), Tunisian Government (50 pct).
United Kingdom:	
Blackdene mill and mines	Minworth Ltd.
Broadwood mill and mines	Do.
Derbyshire Deposits	Laporte Industries Ltd.
United States:	
Annabell Lee	Ozark-Mahoning Co.
Barnett	Do.
Denton	Do.
Henson	Do.
La Plasano	D & F Minerals Inc.
Nye Crowell	Crowell Fluorspar Co.

Table A-2.—U.S. fluorspar properties deleted from study

State and property name	*Reason deleted*
Arizona:	
Red Rock	27,000 mt inferred.
Quartz Ledge	18,600 mt inferred.
Colorado: St. Peters Dome	859,000 mt inferred, and no technology.
Illinois:	
Hastie Quarry	41,000 mt, intermittent.
Heavy Media	Near depletion.
Knight Mine	Do.
Oregon: Rome Tuffs	No technology.

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APPENDIX B.—GEOLOGY, MINING, BENEFICIATION, INFRASTRUCTURE, AND TRANSPORTATION, BY COUNTRY

The following sections give an overview of the fluorspar properties evaluated. Some of the country sections have been abbreviated owing to the large amount of material previously published. Countries with minimal published literature contain more detailed, site-specific information obtained during the course of this evaluation. Care has been taken to protect confidential information.

KENYA

Geology

The fluorite deposits of the Kerio Valley are believed to be of hydrothermal origin in the Post-Miocene era, as lavas formed a protective cap over the Precambrian rocks in the area. Three orebodies have been identified and mined in the district (*21*).[1]

The main fluorspar deposit, located at Kimwarer, is the only one currently in production. The Kimwarer ore body is exposed on a series of five hills, four of which have been mined. Stratabound bands of fluorite ore are up to 50 m wide at the surface. The fluorite ore is typically finely crystalline and disseminated through a siliceous matrix with a relatively high phosphorus content. There are virtually no sulfides present in the ore (*21*).

Demonstrated resources of 6.2 million mt containing 41 pct CaF_2 were being reported as of 1983. Inferred resources are present; however, exploration and geologic analysis are not of high priority, and there has been no attempt made to delineate further resources. The current resources are sufficient to support the mine for the next 25 yr.

Mining and Beneficiation

The open pit mine currently in production has a production capacity of 1,600 mt/d and is limited by the mill capacity. During the period 1980-82, an average stripping ratio of 1:1 was experienced with 250,000 mt/yr each of ore and waste produced. There is no ore dilution, and 100 pct of the reserves are recoverable.

The Kenya Fluorspar Co. Ltd. (KFC) beneficiation process involves crushing, grinding, flotation, and dewatering. The plant utilizes an all-flotation process rather than utilizing a prebeneficiation method such as heavy media separation. When KFC took control of the operation in 1979, it closed the metallurgical-grade plant because of problems encountered by the previous owner, Fluorspar Co. of Kenya. Capital was then diverted to revitalize the acid-grade facility.

Tailings flow by gravity to an impoundment located 1.2 km from the mill. The plant requires 600,000 gal/d of water, all supplied as fresh water. There are no facilities to recirculate the water from the mill at present.

The acid-grade filter cake is trucked by contractors 45 km to a railhead at Kaptagat and from there railed 884 km to the port of Mombasa on the Indian Ocean.

Infrastructure

Transportation facilities and utilities were in place when KFC acquired the property in 1979. Included was a water clarification and filtration facility for the nearby river that supplies water to the mill. Electricity is suppled by the East African Power and Lighting Co. Ltd. and a transformer substation at the concentrator reduces incoming power.

Currently, housing, schools, recreation facilities, and medical care are provided by the company. All roads in the vicinity of the mine are maintained by the company, as well as an all-weather dirt airstrip for light aircraft (*21*).

The port facilities at Mombasa are in need of improvements. KFC will not be responsible for these costs, as Bamburi Portland Cement Co. is planning to spend $2 million on a new port facility. KFC has built a new 20,000-mt-capacity storage terminal at the port with a railcar off-loading area and reclaim facilities to tie in with the existing ship loader (*21*).

MOROCCO

Geology

Country rock of the El Hammam region consists of a series of schists and gneisses, with limestone lenses. Structure in the area is a NE-trending syncline. Numerous calcite veins cut the country rock in the mine area. Local skarn metamorphism is attributed to a granite outcrop in the bed of the Qued Beth River nearby. Two major periods of folding have been identified. Intrusion of the veins is associated with the later folding.

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[1] Italicized numbers in parentheses refer to items in the list of references preceding appendix A.

The ore occurs as lenses in the calcite veins cutting the schist and consists of crystalline fluorspar varying in color from clear to green and violet, with accompanying silica, calcite, and minor sulfides. Strongest fluorspar mineralization is located at the vein intersections as more or less tabular en-echelon lenses.

Mining Methods

The principal mining method is shrinkage stoping. At the time of the site visit, mining was taking place on two levels, with six active stopes, three in extraction, and three in development. Production was about 800 mt/d ore, with 200 mt/d waste.

At 800 mt/d, 300 d/yr, mine production should be 240,000 mt/yr. However, this rate has not been achieved, and for the purpose of this evaluation, an average rate of 203,000 mt/yr was assumed. This figure was determined by averaging production for 1979-81.

Development plans call for the deepening of the present mine levels; backfilling of old stopes is under investigation to insure stability as mining progresses to deeper levels. Backfilling has been initiated in a few stopes. If conducted on a full-scale basis, backfilling would raise the cost of mining and might be uneconomical if current weak market conditions persist.

Table B-1.—Annual production of acid-grade fluorspar for El Hamman, 1980-82

Year	Ore treated, 10^3 mt	CaF_2 10^3 mt
1980	196	66
1981	215	68
1982	156	50

Beneficiation

Ore is hauled from the mine by truck or train from the adit portals, a distance of 100 to 500 m. Ore is crushed and run through the heavy media plant for upgrading prior to flotation. Recent annual output of acid-grade concentrate is shown in table B-1.

All of the concentrate produced is sold as filter cake in export markets. Acid-grade fluorspar is trucked by the Office Nationale de Transport 65 km to the rail siding at Meknes. The Office Nationale de Chemin de Fer rails the concentrate 271 km to the ocean port at Casablanca.

Infrastructure

Water for the operation is pumped from the Qued Beth, a major river 6 km from the site. Electricity is supplied by a 42-km, high-tension line completed in 1974. A 16-km paved highway linking to the Meknes highway was completed in 1975.

SAMINE, owner and operator of El Hammam, built a town for the workers and a small satellite community of villas for the staff. Both are supplied with domestic water from a filtration plant installed for that purpose. Amenities include an infirmary, schools, a mosque, a community building, and a cantina. Food stocks are brought in twice a week from Meknes.

NAMIBIA

Geology

The shape of the ore bodies can be described as limestone replacement deposits, lenticular in shape, from low to vertical dip following the attitude of the folded formations. The principal geologic influence is the presence of an alkaline volcanic pluton, the source of the hydrothermal solutions. The fluorspar deposits occur on the flanks and crests of a 2.5-km-long, crescent-shaped ridge that rises 330 m above the surrounding flat plain.

Fluorspar occurs not only as replacements of limestone, but also as fracture fillings in sedimentary rocks and metasomatically altered sedimentary rocks that form the southern rim around an alkaline intrusive complex. Mineralization occurs in steeply dipping fractures in graywackes and meta-graywackes. Fluorspar also occurs in veinlike zones of brecciation as fracture fillings by fluorite and quartz, with gradational to irregular contacts with the country rock. The veins range in width up to 25 km and can be traced over distances as great as 300 m.

The fluorspar consists of a relatively coarse mixture of fluorite and quartz, with minor calcite and apatite. The CaF_2 content of the veins ranges up to 83 pct and average 40 pct. Phosphorus ranges up to 7.5 pct and averages 1.2 pct P_2O_5. Drilling programs on both properties have delineated demonstrated resources of 7.9 million mt with an average grade of 50 pct CaF_2.

Mining and Beneficiation

Aside from a modest amount of open pit mining and a small adit on the ore outcropping on the IMKOR side, there has been no mine development in the area, and no mill facility has been built. The proposed mining plan for this evaluation calls for a limited size open pit mine of 500 mt/d, feeding a small commercial-sized mill, and a 1988 startup date was assumed. The size of the operation would permit further experimentation on high-phosphate ores, since concentrates made in test work to date do not meet general market specifications for acid-grade fluorspar.

High phosphorus content and the siliceous nature of the vein ores point to all-flotation milling. The most probable product would be a high grade metallurgical fluorspar (93.5 pct CaF_2). The high grade would be required to offset the penalizing effect of the high phosphorus content. As briquettes do not travel well by sea, it may be assumed that filter cake is the most likely form of the product.

Although surface methods would be used initially, it is likely that underground mining techniques would be used to exploit deeper ore bodies in the future. Additional drilling would be needed from the floors of open pits. Currently, insufficient deep drilling exists to properly delineate the deeper ore bodies.

Infrastructure

It will be necessary to construct and maintain a heavy duty gravel road 12 km to the rail siding at Otjikango, which then gives access to a present highway to Otjiwarongo, the closest commercial center. Some of the workers would need to be housed on a compound near the mine; however, workers from two neighboring tribes could be bussed from nearby towns.

Water is available for milling purposes from the Ugab River to the northwest, but additional well water resources will be needed. Power lines from Otjikango to the site will also be required.

REPUBLIC OF SOUTH AFRICA

Geology

Bushveld Igneous Complex

Buffalo

The Buffalo fluorspar deposits occur in leptites, felsites, and the Bushveld granite of the Bushveld Igneous Complex. The origin of the Buffalo fluorspar deposits is related to the intrusion of the Bushveld granite into the felsite country rock, which was metamorphosed in the lower most parts to form the leptite xenoliths that host the economic concentrations of fluorspar. Minable quantities of fluorspar are found in the leptite host rock and occur in the form of simple or composite veins. The fluorspar mineralization varies from dark purple to pale green and occurs as parallel and subparallel veins located predominantly along bedding planes, fractures, and certain joints in the leptite (*35*).

At Buffalo, five ore bodies have been mapped to date: North, Mill, South, East, and Central. As of 1984, the first three of these ore bodies were being mined. With demonstrated reserves of 4.5 million mt contained CaF_2, the operation could run for over 15 yr at the current capacity of 240,000 mt/yr (*2*).

Vergenoeg

The Vergenoeg deposit, one of the largest in the world, is located within an area consisting of acid epicrustal Rooiberg felsite, capped by a succession of pyroclastics from early volcanic activity. The Vergenoeg ore body lies at the intersection of numerous major faults and fractures. It is believed that the present ore body was formed in the Vergenoeg volcanic vent, through which late-phase mineralizing fluids passed. At the time the Bushveld granite was emplaced, the Rooiberg felsite formed a cover entrapping mineralizing gasses and volatiles collected through fissures and fractures, resulting in explosive eruptions and the Vergenoeg vent (*35*).

The hematite-fluorspar mixed ore consists of coarse-grained fluorite granules and masses set in a matrix of fine grained amorphous hematite. The fluorspar is colorless to light green, often displaying iron staining along cleavage planes. The CaF_2 content of the entire ore body averages 35 pct, but ranges from 20 to 60 pct (*35*).

Kruidfontein

The Kruidfontein structure is classed as a carbonatite, and a high-level volcanic complex forming an integral part of the Pilansberg Province. The Kruidfontein volcano is situated in a large horst structure known as the Crocodile River fragment, a block of Pretoria Series and Dolomite Series sediments of the Transvaal system. It has been suggested that the fragment may represent an erosional remnant of a roof pendant within the Bushveld Igneous Complex. Rock types comprising the volcano are predominantly extrusive altered tuffs, pyroclastic breccias and flows, as well as some small intrusives. Many of these exhibit strong bedding, which dips towards center at angles commonly ranging from 10° to 40°.

The volcanic complex is made up of two main elements: an outer rim, and an inner zone separated by a zone of tuffs and pyroclasts that is less resistant to erosion and forms a circular trough between the two main features. The outer rim consists mainly of ignimbrite and pyroclastic breccias, with andesite and trachyte, and apparently lacks mineralization. The inner zone is made up of a rhyolite unit and a sovite unit. The rhyolite outcrops on the western, southern, and eastern section of the complex but is absent in the northern portion. Fluorite is found in veins, vugs, stockworks, and dissemination, but to date has not been found in economic concentrations. Sovite, a type of welded tuff, outcrops predominantly on the northern portion of the volcano, forming a continuous arcuate zone, and rests conformably on older pyroclastic breccias of the outer rim. Layered beforsite, essentially a dolomitized sovite, is the principal host rock for fluorite.

Groot-Marico District

The fluorspar deposits in the Groot-Marico District generally occur as large stratabound bodies in a well-defined dolomitic limestone unit. From a genetic viewpoint, the Groot-Marico fluorspar deposits are regarded as large, bedded replacement bodies of the classical Mississippi Valley type. Three main types of fluorspar ore are recognized in the Marico district: dolomitic or algal ores, rockspar, and residual ore (wad). Other types include blockspar, banded spar, and breccia spar. In replacement zones, fluorspar may occur as blebs, irregular stringers, or subparallel or folded lenses, and is generally white or light gray. Associated minerals are calcite, quartz, tremolite, talc, and sulfides. Coarse fluorspar also occurs as infilling of solution cavities and fracture zones in the dolomite. Mineralization is affected by north-south minor faulting and diking, which appears to have led to brecciation and favorable sites for deposition of the higher grade ores.

Witkop

The fluorspar mineralization at Witkop occurs in bedded replacement deposits that are associated with dolomites of the Middle and Upper Frisco Zones. These deposits appear to be elongated along a general north-south trend and straddle what is thought to be a major fault or fracture zone that was intruded by a dolerite dike.

The most abundant ore type at Witkop consists of dolomitic or algal ores ranging from 8 to 40 pct CaF_2. Minor amounts of sulfides, mainly pyrite, also occur with the ore. "Rockspar ore" also occurs at the Witkop mine and is generally higher grade (40 to 75 pct CaF_2). The largest deposits, at the South Hill Pit and in the Main Pit area, appear to be related to fluorspar replacement of block-faulted banded chert or banded chert laid down as younger karst-filled deposits. The other type of ore present at Witkop is eluvial ore. In the northeastern portion of the main deposit and along the line of the valley draining the area, the mineralized dolomite has been almost completely dissolved over an area 100 by 600 m, and high-grade ore (approximately 40 pct CaF_2) has been eluvially concentrated in the residual soil. The current demonstrated resources of 6.6 million mt contained CaF_2 are sufficient to support the adjacent mill at present levels for over 50 yr.

Marico

Two main types of occurrence, breccia spar (dolomitic spar) and wad ore (kokerman), were mined from stratabound deposits containing stromatolite structures in the

Middle Frisco zone. The average thickness of the Main Productive Horizon is 12 m and is the same for both the breccia spar and wad deposits. The average fluorspar grade, expressed in mass percent, is about twice as high in the wad deposits as in the breccia spar, owing to the difference in the relative density of these two types of deposits (*35*).

High-grade rockspar ore may range from 40 to 75 pct CaF_2. Where weathering has eluvially concentrated this ore at the surface, it was the source of metallurgical gravel spar for many years, prior to construction of flotation milling facilities.

Transvaal

The mineralization is elongated in a north-south trend in the district, which extends for about 25 km along the strike of the Archaean dolomite formation. Fluorspar replacement occurs in the Middle Frisco dolomite, almost exclusively within an algal-rich dolomitic horizon that exhibits a high degree of stratigraphic conformity.

The fluorspar bodies occur as lenses or irregular lens-shaped bodies, described as metasomatic replacement type deposits commonly associated with lead and zinc ores. Associated minerals include calcite, quartz, pyrite, and minor quantities of pyrrhotite, galena, sphalerite, and chalcopyrite. Current estimates place demonstrated reserves at 27 million mt grading 21 pct CaF_2.

The deposit dips 5° to the north and is overlain by approximately 20 m of unmineralized dolomite and 20 m of chert, quartzite, and shale of the Penge Iron Formation. Owing to the depth of the overburden, Transvaal is the only fluorspar operation in South Africa planning to utilize underground mining methods.

Mining Methods

All but one of the fluorspar deposits in South Africa use or plan to use conventional open pit mining methods. Benches range from 2.5 m in weathered rock to 13 m in harder rock. The average stripping ratios for Buffalo, Witkop, and Vergenoeg are low, ranging from zero at Vergenoeg to 1:1 at Buffalo. Most of the ore at Marico is under 10 to 15 m of overburden; overburden at Kruidfontein will range from 0 to 20 m. Haulage distances from the mining area to the mill are less than 1 km at Vergenoeg, 1 km at Witkop, 1.5 km at Buffalo, and up to 12 km at Marico.

Marico experiences highly variable mineralization, and that, combined with the overburden, required that shallow sample drilling be performed ahead of mining at closely spaced intervals. After the overburden was drilled and blasted, it was backfilled into worked-out open pit space wherever possible. The cost of overburden removal, sample drilling, backfilling, and the distance of the haul to the mill greatly increased Marico's mining cost. These factors contributed to the closure of the mine in August 1982. Demonstrated resources of over 4.7 million mt contained CaF_2 remain to be exploited; however, the operations are not likely to resume until there is a substantial recovery of the fluorspar price, according to management.

Current plans are to mine the Transvaal ore body by means of a mechanized room-and-pillar system, the rooms being 9 by 9 m and the pillars 8 by 8 m. Annual mine output is scheduled to be 1 million mt with an overall mining recovery of 70 pct (*35*). A 1987 startup date was assumed for this evaluation.

Table B-2.—Annual capacities and fluorspar products for the Republic of South Africa

Operation	CaF_2 grade, 10^3 mt		
	Acid	Metall.	Ceramic
Installed:			
Buffalo	206	24	10
Marico	130	0	0
Vergenoeg	115	0	0
Witkop	82	0	0
Total	533	24	10
Proposed:			
Transvaal	183	0.	0
Kruidfontein	310	36.5	18
Total	493	36.5	18
Grand total	1,026	60.5	28

At Transvaal, the primary crusher will be located underground at the base of the decline and will feed crushed ore onto the suspended ore conveyor. Dump trucks will transport ore from the working faces to the crusher station. A pumping station will be excavated near the crusher station to handle expected mine water drainage.

Beneficiation

All of the producing operations in South Africa employ normal fluorspar flotation processes. A magnetic separation stage follows flotation at two of the plants. The Buffalo mill has to remove phosphorus-bearing monazite, and the Vergenoeg mill reduces excess iron ore that may be present. Refer to table B-2 for the current rated capacities of the mills and the products produced. It should be kept in mind that while these are the rated capacities, the operations are currently operating at reduced rates.

All of the properties have adequate water supplies and recirculate an average of 65 to 75 pct of their tailings water through the mill. The Vergenoeg mine has its own fresh-water dam on site to supplement the recirculation of flotation plant water (*35*). Water requirements for the Marico-Groot District are provided by the Zeerust Municipality. Power for the mines and mills is supplied by Escom, the Electricity Supply Commission.

In response to recent drought conditions in southern Africa, Buffalo undertook a program to dam surface water on its property and funded a $500,000 improvement in storage capabilities for the municipal system. These actions have left the mine with adequate operating supplies even in a severe drought (*2*).

The metallurgical processing plant at Transvaal has been designed to utilize state-of-the-art flotation processes as perfected at other facilities in the vicinity. The design capacity of the concentrator is 3,000 mt/d with an average CaF_2 content of 20.6 pct. An average recovery of 86 pct has been planned, with an overall product grade of 97 pct CaF_2. The acid-grade product will be trucked to Zeerust, transferred to rail, and transported to the port at Durban.

The Kruidfontein ore consists of very fine grained fluorite in carbonatized volcanics. The preliminary metallurgical studies performed on diamond cores and percussion drill chips have indicated that prebeneficiation by gravity methods is not promising. This indicates that total flotation will be required with special attention paid to stage grinding and avoidance of sliming. Recovery of metallurgical- and ceramic-grade products will assist in making salable products of flotation middlings that would otherwise not meet acid-grade specifications.

Metallurgical tests on the Kruidfontein ore have achieved acid-grade fluorspar at a recovery of 60 pct. Acid grade

Table B-3.—Annual production statistics for acid-grade fluorspar, Hamman Zriba, 1976-83

	Acid-grade CaF$_2$, 10^3 mt		*Acid-grade CaF$_2$ 10, mt*
1976	15	1980	32.9
1977	25	1981	32
1978	29	1982	34
1979	32.5	1983	38*

*Estimated.

(97 pct CaF_2) was achieved by using a weak HCl acid leach. Since the acid leach substantially increased the cost of extraction, other alternatives, such as the wet, high-intensity magnetic separation (WHIMS) techniques used at the Buffalo plant, may be evaluated. A recovery of greater than 70 pct would need to be achieved for the deposit to be considered viable. As proposed for this study, the Kruidfontein beneficiation plant would have the largest capacity in South Africa.

Another problem with this ore is the presence of about 1 pct phosphorus. The maximum allowable specification for acid-grade is 0.03 pct P_2O_5. The acid leach has also been successful in reducing the phosphorus level to the specified 0.03 pct; however, the reduction of phosphorus may be the major cost factor in milling this ore.

TUNISIA

Geology

The Hammam Zriba fluorspar deposit is a mineralized manto lying at the unconformity between Upper Jurassic Portlandian limestone (footwall) and Upper Cretaceous Campanian limestone (hanging wall). It outcrops for a distance of about 1 km in the walls of a steep-sided canyon, known as Defile de Ache, on the northeast flank of the Zaghouan Mountains.

The deposit parallels the bedding of the limestone, dipping away from the canyon axis. Structurally it is a "horst coupee," signifying the control of the canyon as an uplifted structural block broken by a medial fault. The ore shows pronounced banding of fluorite and barite in alternating layers. Currently, fluorite grades range from 27 to 30 pct CaF_2, and barite grades from 40 to 45 pct $BaSO_4$.

Various explanations have been offered for the origin of the ore, the most accepted being mineralized hydrothermal solution percolating along the unconformity, possibly introduced through the axial fault. It appears to be similar in origin to the fluorspar mantos in Coahuila, Mexico, at the Boquillas horizon at the top of the Santa Elena (Cretaceous) limestone, but those have more celestite ($SrSO_4$) rather than barite ($BaSO_4$) as the principal sulfate constituent and lack the base metal (lead-zinc) component. Otherwise, structurally and morphologically, the two are similar.

Mining and Beneficiation

Initially, quarry production began in 1962. Underground mining began in 1969 and became mechanized in 1978. Mining is by room and pillar methods, and the 1983 mine program called for an annual production of 250,000 mt, (25,000 mt waste and 225,000 mt ore). Mining extraction recovers 85 pct of the in-place ore; 15 pct is left as pillars. The average grade is generally maintained at 27 pct CaF_2.

Normally, mine water is negligible, but heavy rains raise the water table and thermal springs flood down-dip workings at the southeast end of the mine. During flooding, pumping is required at a rate of 250 m^3/h.

The mill is located within 500 m of the mine portals. Ore is crushed and undergoes normal flotation to produce acid-grade concentrates. The flotation circuit was redesigned in 1977-78 to increase feed capacity from 350 mt/d to the present 800 mt/d. The planned rate of 41,000 mt/yr acid-grade concentrate has yet to be reached and may be too close to the mill's rated capacity of 42,000 mt/yr to be practical. Table B-3 shows acid-grade production figures for the mill since its startup in 1975.

Presently, the high barite content of the mill feed results in tailing with 60 pct $BaSO_4$. These tailings could be a valuable coproduct in the future, and plans are also being discussed to recover a bulk lead-zinc sulfide concentrate. Weak markets are delaying the implementation of additional circuits.

If one, or both, of the two prospective deposits becomes available, FLUOBAR may expand its current capacity from 42,000 mt/yr to 80,000 mt/yr. However, poor market conditions for acid-grade fluorspar may make it difficult for FLUOBAR to find a partner to help finance the expansion.

All of the concentrate from Hammam Zriba is sold to ICF for conversion to aluminum fluoride at its plant in Gabes. During 1982, the conversion factor was 1.6 mt CaF_2 per metric ton AlF_3. Recession in the European aluminum industry made apparent the problem of dependence on a single outlet and industry (aluminum). ICF is reportedly considering the use of FLUOBAR's acid-grade fluorspar to make HF and possibly fluorocarbons.

Infrastructure

Electricity is suppled by a regional net, called STEG. Housing, schools, and a mosque are provided for the workers and staff. All other amenities are available in the town of Zaghouan, 10 km away.

CHINA

Geology

Hubei Province

The Hong An ore body is a vein with an average width of 8 m, ranging up to 21 m. Country rock is a rhyolite porphyry. Gangue minerals include quartz and calcite. No sulfides are present. The district as a whole reportedly has over 5 million mt of probable resources with an average grade of 70 pct CaF_2.

Inner Mongolia

The Da Gai Tang ore body is a vein striking north-south, grading 70 pct CaF_2. Other vein minerals include quartz and calcite. The country rock is an acid volcanic tuff, considered to be Jurassic in age, which has been intruded by granitic rocks to the north of the mine.

The ore body at Hei Shao Tou is a vein striking east-west and dipping 65° to the south in crystalline gneissic schist, grading about 70 pct CaF_2. The vein is parallel to foliation. A cross-fault offsets the vein to form two sections. Fluorite also occurs in the area as veins and disseminated mineralization in siliceous limestone, as well as in the schist, and is also prominent in the nearby iron mines.

Jiangxi Province

At De An, fluorspar occurs as four limestone replacement bodies along a prominent fault zone. The ore bodies are designated by the numbers 1 through 4, with ore bodies 1 and 2 grading 40 pct CaF_2. Geologic exploration underway on ore bodies 3 and 4 is expected to delineate much larger resources than in ore bodies 1 and 2.

Shandong Province

Ore in the Pong Lai district occurs as vein-fillings of faults and fractures in granite country rock. Vein material consists of fluorite, calcite, and silica. Sulfides are sparse, chiefly appearing as finely divided pyrite. Six other mines in the district are said to be geologically similar to Pong Lai. A total of 23 veins have been identified in the district, which covers an area of 100 km². Resources for the district are not fully defined, as the area has not been systematically explored.

Zhejiang Province

The Wu Yi district is the most intensely mineralized in all China's known fluorspar areas and is also the most developed. The mines are on a series of en-echelon veins that strike approximately east-west to form the en-echelon patterns. The veins occupy a fracture system in a porphyritic acidic tuff country rock. Vein materials consist of fluorite, calcite, and silica. Sulfides are negligible.

A geologic team operates in the district, mapping and drilling on a continuing basis. Zhejiang Province has 60 locations currently in production, although most are on a modest scale, producing hand-sorted metallurgical lump by local communes. The 13 mines that feed the Dong Feng mill were included in this evaluation. Fluorspar has been found in 144 locations in the province, denoting a long-term potential beyond the life of demonstrated resources in the Wu Yi district itself.

Mining Methods

Most of the mines in China use underground shrinkage stoping methods to recover ore from their vein ore bodies. Stopes are usually left open and not backfilled. Mines are labor-intensive, as shown by the lack of mechanization; ore cars are typically hand-trammed and metallurgical grades of fluorspar are produced by hand-cobbing methods. The metallurgical lump is normally produced in grade increments from 80-85 pct to 90-95 pct CaF_2, with some lower or higher grades specially produced from certain mines for specific customers. Resulting low grade "broken pieces" are used for feed at the flotation mills.

Initially, the veins in the Hong An and Wu Yi districts were mined by open pit methods and eventually went underground, where shrinkage stoping methods were used. The Hong An district usually backfills the stopes. Ore production at mines in the Wu Yi district is scheduled to increase from 450,000 to over 537,000 mt/yr to accommodate an additional flotation circuit installed in 1983.

Mining in the De An district began in 1959 with small open pits producing roughly 20,000 mt/yr. Substantial expansion in the mid-1970's took place, and currently two open pits are being worked on ore bodies 1 and 2. Both mines have 10 faces being hand-mined simultaneously. Operating with a stripping ratio of 1:1, approximately 135,000 mt/yr ore is produced.

Table B-4.—Annual production capacities and fluorspar products for China, 1983

Mill	CaF_2 grade, 10^3 mt		
	Acid	Metall.	Ceramic
Bai Yun He Pe	[1]5	5	0
De An	[2]20	15	3
Dong Feng[3]	102	200	0
Fu Shan	11.5	(4)	0
Hong An	39	50	0
Hua De	6	25.6	0
Xian Shan	12	37	0
Total	195.5	332.6	3

[1] Could double production with idle equipment.
[2] Could expand to 50,000 or 100,000 mt/yr as ore bodies 3 and 4 are developed.
[3] Pellet plant with capacity of 30,000 mt/yr idle since 1977.
[4] Metallurgical production included with Xian Shan.

Beneficiation

Metallurgical and ceramic grades of fluorspar are produced with hand-cobbing methods. Acid-grade concentrates are produced from "broken pieces" of low-grade ore rejected from hand-cobbing. The annual capacities for each of the mills evaluated and the grades of fluorspar produced from each associated mining district are shown in table B-4. A brief discussion of the mills and fluorspar produced in each province follows.

Hubei Province

The Hong An mine has historically produced six grades of metallurgical-grade fluorspar in 5-pct increments, ranging from 65-69 pct to 90-94 pct CaF_2. Two higher grades are also produced, 95-97 pct and 98 pct CaF_2. The largest tonnages produced are 80-84 pct and 90-94 pct CaF_2.

A flotation mill was scheduled for completion in July 1983, with a projected capacity of 39,000 mt/yr acid-grade fluorspar concentrate. Mill tailings from the flotation plant will have to be pumped a distance of 5 km to a storage dam. Tailings have to be pumped that distance to avoid contamination of the local lake, which is an important source of fish.

The acid-grade filter cake will be bagged in returnable 1-mt nylon bags, or dried in a coal-fired drier and bagged in 50-kg bags. Products are either trucked 100 km to a rail siding or 137 km to the Chan Jiang River for barging to the ocean port of Shanghai.

Inner Mongolia

From the Hei Shou Tou mine, both acid and metallurgical grades of ore are trucked 35 km to the Bai Yun He Pe flotation mill. The mill, completed in 1970, treats "broken pieces" averaging 60 pct CaF_2 from the metallurgical hand-cobbing operation. If the market warrants, the mill's output could be doubled from the present 5,000 mt/yr utilizing presently idle equipment. All acid-grade is shipped in 50 kg nylon bags; metallurgical lump is shipped in bulk. The acid-grade product is 96 pct CaF_2, which does not meet current U.S. Customs' specifications of 97 pct.

The Hua De mill was idle during the 1983 site visit because of weak acid-grade fluorspar demand. However, the mines continued to operate, and mill feed was being stockpiled. Built in 1982 with Chinese-made equipment, the mill only produced 1,000 mt before operations ceased. The mill is kept ready and could be restarted within 2 weeks. Its rated capacity is 6,000 mt/yr of acid-grade concentrate produced by normal flotation. The flotation concentrate is thickened, filtered, and bagged in 50 kg bags.

Jiangxi Province

Ore from the De An mines is hand-trammed to the wash plant or to ore bins where its trucked to the flotation mill. The wash plant is hand-operated and produces ceramic- and metallurgical-grade products. The flotation mill began production of acid-grade fluorspar in 1981 and has a rated capacity of 20,000 mt/yr. Owing to a weak market, the mill was closed at the end of 1982, but was scheduled to reopen by March 1983. The operation also has a coal-fired dryer available.

As the fluorspar market improves, plans are to expand the De An flotation mill to produce 50,000 mt/yr acid-grade concentrates. If ore bodies 3 and 4 prove out as hoped, the mill could be expanded to 100,000 mt/yr.

Some of the concentrates are bagged using 25- and 50-kg woven plastic bags with a waterproof plastic insert. Large nylon bags holding 1 mt are used for bulk shipments of acid-grade concentrate.

Shandong Province

The Fu Shan mill was built as a copper mill in 1958, and converted to fluorspar flotation in 1981. Only one-third of the original copper capacity is being used for the fluorspar operation. Acid-grade concentrates are trucked to port or rail at Yan Tai, which is 25 km from the Fu Shan mill.

The Xian Shan mill was originally an iron ore flotation mill, built in 1968. In 1981 it was converted to make acid-grade fluorspar. The conversion required new flotation cells, boiler, conditioner tanks, and a filter; otherwise, existing equipment was used.

Acid-grade filter cake is stored in bulk or in 1-mt returnable nylon bags, which are used to transport the product to port. The metallurgical and acid-grade products are trucked to port or rail at Yan Tai, 95 km from Pong Lai and 37 km from Xian Shan.

Zhejiang Province

After hand-cobbing at Wu Yi mines to obtain metallurgical-grade lump, the remaining ore (225,000 mt/yr) is fed through the Dong Feng acid-grade mill. With the new flotation circuit installed in 1983, the mill capacity will be 102,000 mt/yr of acid-grade concentrates. A pellet plant has a capacity of 30,000 mt/yr of 90-pct-CaF_2 pellets, but has been idle since 1977. Oil-fired dryers are available to dry acid-grade for use in the domestic HF industry.

Infrastructure

Electricity is supplied from a regional net, and coal from local mines supplies heating needs. Tailings impoundments are generally adequate for 20 yr of production at current rates. Most equipment is Chinese made and maintained.

Transportation

Fluorspar is consumed domestically by the steel, aluminum, and fluorocarbon industries, and is exported to Japan, Europe, and to United States; undetermined amounts also go the North Korea and the U.S.S.R. The Chinese Government pays a bonus for exported material earning foreign exchange (yuan 30/mt, or $15/mt). The ceramic-grade fluorspar produced from De An, and acid-grade products from Bai Yun He Pe and Hua De, currently do not meet U.S. Customs' specifications, and therefore these particular products are not be exported to the United States.

Table B-5.—Transportation methods and distances from Chinese fluorspar mills to ports or point of consumption

Mill	Destination	Distance km	Method
Hua De	Tianjin	600	Rail.
De An[1]	Railhead	30	Truck.
	To Jiu Jiang	50	Rail.
	To Shanghai	775	Barge.
Bai Yun He Pe[2]	Railhead	85	Truck.
	To Tianjin	1,020	Rail.
	To Bao Tou	150	Do.
Hong An[3]	Wuhan	137	Truck.
	To Shanghai	1,000	Barge.
Fu Shan	Yan Tai	25	Truck.
Xian Shan	..do	37	Do.
Dong Feng	Jinhua	31	Do.
	To Shanghai	420	Rail.

[1] Products trucked to railhead, railed to Jiu Jiang, then barged to Shanghai.

[2] Products trucked to railhead, then railed to Bao Tou for domestic use, or to Shanghai for export.

[3] Products trucked to Wuhan, then barged to Shanghai.

For this evaluation, it was assumed that all fluorspar is exported through three major ports: Tianjin, in Tianjin Shi; Shanghai, in Jiangsu; and Yan Tai in Shandong. These are among the 11 first-class harbors in China. Yan Tai can berth 12 ships at one time and guarantees a loading rate for fluorspar of 1,200 mt/d, weather permitting.

Inside the harbor at Shanghai the water is deep and ice-free all year round, but 10,000 mt ships must wait for high tide at the estuary of the Woosung River. Ships of 5,000 to 6,000 mt can enter at any tide. About 100 ships can berth simultaneously along the line from Woosung to Manlitsui. Wharf facilities are good, and loading and discharging facilities are partially mechanized.

Tianjin is 44 nautical miles from the estuary of Hai Ho River. Two other ports, Tangku and Hsinkang, are only 13 nautical miles from the estuary. The harbor group formed by these three ports is the third busiest in China. The channel approach is narrow, winding, subject to constant silting, and ice-bound for 3 months of the year. Despite continuous dredging, the channel is at best open to vessels with 4.5 m draft. Vessels up to 99.05 m in length can proceed up to Tianjin via lock to Hai Ho. Mechanical loading and discharging facilities are available.

Table B-5 lists the distance, method of transportation, and destination of fluorspar products from the seven mills evaluated. Transportation costs run the equivalent of $0.05/mt-km for trucking, $0.015/mt-km for rail, and $0.005/mt-km for barging, in 1982 U.S. dollars.

THAILAND

Geology

Fluorspar occurrences in the northern sector tend to be in limestone terrain at or near granitic bodies, often as veins in faults or along limestone-granite contacts, although they also occur as veins with granite on both walls (*12*).

Limestome in the middle sector, at Phanom Thuan, appears as horses in the ore body, indicating it to be a replacement of limestone in a predominantly paragneiss-schist terrain, here intruded by a pegmatite alongside the ore. At Salak Pra the country rock is wholly limestone, and the veins appear to be epithermal. The ore at Takien Ngam is along a granite-limestone contact, with subsidiary mineralized showings in both rock types adjacent to the vein. At Tao Dam the ore is wholly within granite (*12*).

The main ore body in the southern sector at Krabi occurs as fracture-filling in a series of interbedded shales and quartzitic sandstones, with pods of limestone, overlying a massive limestone. Nearby the collapse breccia of a limestone sinkhole is mineralized, indicating late origin of that fluorspar emplacement or a late remobilization (*12*).

Given these geologic conditions and relating them to the geology of the world's largest fluorspar ore bodies, it is not unlikely that large limestone replacement mantos remain to be discovered in a suitable limestone host. Also a major vein in granite is a possibility, similar to the large Osor ore body in northeastern Spain.

Demonstrated resources are defined only through the late 1980's at most of the sites, while a few have adequate resources to last until the early 1990's. Takien Ngam was the only operation with sufficient reserves outlined to continue mining beyond the year 2000. At the time of the site visits in 1983, Thaivat Mining Co. had just retained the services of a geologist to define additional resources at its Tao Dam mine. However, most of the operations continue along easily identifiable traces of fluorspar, and organized exploration has not been a part of Thailand's mining plans until recently. Buyers looking for reliable sources of fluorspar are encouraging some of the companies to initiate exploration programs. For the purposes of this evaluation, resources become depleted within the next 10 yr; however, it is unlikely that this will be the case.

Mining Methods

The operations of Thailand utilize both open pit and underground mining methods. The operations at Phanom Thuan, Takien Ngam, and SK Minerals are mined from open pits; while Mae La Luang and Salak Pra utilize open stoping. Tao Dam uses both shrinkage stoping and open pit methods to meet production levels. All utilize hand-mining and hand-sorting techniques, with minimal crushing done by jaw crushers at a few of the sites. The Mae Tha District is largely depleted, but Universal Fluorspar Mining (UFM) had about 1 million mt of tailings to reprocess at the site.

Phanom Thuan has demonstrated reserves of 300,000 mt, but the remaining reserves occur 18 m below the present pit floor, which is at water level now. Continued operation of this mine will depend on the company's ability to handle pumping problems and the associated costs. For this evaluation, the entire reserve was considered minable, allowing for production into 1987.

Independent miners are an important source of ore; most of the ore is obtained by hand methods, in some cases from sites considered to be depleted by the larger mining companies. Ore is sold directly to the companies operating acid-grade mills, or to intermediate companies which sell metallurgical-grade products or acid-grade feed. Thepnithi is one such intermediate company with a 5-yr contract to supply metallurgical products to the U.S.S.R. Having essentially depleted its own reserves, Thepnithi now buys its fluorspar from other producers, usually independents.

Table B-6.—Annual capacities and fluorspar products for Thailand, 1983

Operation	CaF_2, 10^3 mt	
	Acid	Metall.
SK Minerals	[1]22	0
Thai Fluorite Processing Co.: Ban Lard	47	0
United Fluorspar Co.:		
Salak Pra	([2])	6
Takien Ngam	0	15
Universal Mining Co.:		
Mae La Luang	0	21
Mae Tha	0	30
Phanom Thuan	([3])	15
Total	69	87

[1] Additional capacity installed doubled 11,000 mt.
[2] Acid-grade feed (9,000 mt) to Ban Lard mill.
[3] Acid-grade feed (15,000 mt) to Ban Lard mill.

Beneficiation

Five of the operations evaluated produced metallurgical-grade products. These products were hand-sorted and/or screened to meet product grades. Beneficiation was not required for these products. Two companies produce acid-grade concentrates, Krabi International Fluorite Co. (KIF), also know as SK Minerals; and Thai Fluorite Processing Co. (TFP). TFP is the operator of the Ban Lard mill through its affiliate, Thaivat Mining Co.

The SK Minerals heavy media plant and flotation mill was moved from Germany to Thailand in 1977-78 and has been producing acid-grade fluorspar since 1979. Additional capacity at the mill was nearly completed in early 1983. This will double monthly current feed capacity from 4,000 to 8,000 mt. Assuming doubling of the best year's production (11,000 mt in 1982), future output could be 22,000 mt/yr acid-grade products.

Ban Lard acid-grade fluorspar mill was built in 1972 as a joint venture by Jalaprathan Cement Co. and Kaiser Cement and Gypsum. Thaivat Mining Co. bought the mill in December 1980. The flotation mill has a rated capacity of 54,000 mt/yr acid-grade fluorspar, however, it has been operating at reduced levels because of the weak fluorspar market. A production level of nearly 47,000 mt/yr acid-grade was assumed for this evaluation.

At 72,000 mt/yr, Tao Dam supplies approximately one-half the feed required by the Ban Lard mill. S.L. Mining Co. purchases ore from other miners to supplement Tao Dam ore; in January 1983, ore was obtained from 12 other producers. This contributes to the current difficulties faced by TFP in controlling the mill feed. If exploration proves additional resources, Tao Dam will attempt to supply all of the feed material to Ban Lard in the future.

Table B-6 lists the annual capacities and products produced from the Thai operations. This table represents capacities, not actual production rates, which have been lower because of weak fluorspar markets.

FEDERAL REPUBLIC OF GERMANY

Geology

Fluorspar is found in vein structures in the northern Black Forest region of West Germany. In this region, host rocks are cut by over 60 veins, principally barite and oxide iron ore. In contrast, the fluorite vein's mineralization is more than 90 pct fluorspar and quartz-chalcedony, the rest being barite, siderite, and dispersed traces of sulfides.

Strong brecciation is a common feature thought to have occurred in two phases, each accompanied by renewed mineralization introduced in fracturing of the originally emplaced fluorspar.

Veins containing fluorspar and barite are located in a gneiss complex in the central regions of the Black Forest. The mineralization is assumed to have occurred during late Tertiary tectonic fracturing of the host rocks, though some students of the area place mineralization as Upper Carboniferous age.

Mining and Beneficiation

Sublevel caving and stoping methods with cemented backfill are employed. FSP has a flotation mill on the Rhine River by the city of Karlsruhe. The mill treats ore from Kaefersteige, Gottesehre, and purchased ores from France and Spain. The product is an acid-grade concentrate which supplies the parent company's (Bayer) hydrofluoric acid (HF) operation in Leverkusen. The concentrates are barged on the Rhine River from the mill to the HF plant.

Sachtleben Bergbau's flotation mill is located near Wolfach, and the original barite operation was modified to include fluorspar recovery as well. This mill produces acid-grade fluorspar concentrates, with minor amounts of a ceramic-grade fluorspar, as well as several barite products. Sachtleben has no captive use for the fluorspar and sells it to domestic consumers and to the Netherlands. An occasional shipment of raw ore may be sent to FSP's mill.

FRANCE

Geology

Escaro

Denain Anzin operated open pit iron mines at the Escaro site for many years. The open pit operation was preceded by much underground drifting in two parallel related ore bodies, the Sahorre on the east and Escaro to the west. The longest structure, Pla-Ma-Gante, is the only remaining ore body in operation.

Fluorspar was not recognized until 1957 and was believed to be white quartz lying alongside the iron ore, an earthy hematite. Subsequently, the old iron mine drifts were reentered and much exploration drifting was done in the old workings for fluorspar. The ground is said to be undrillable, rotten schist.

The fluorspar and iron ore follow bedding planes in Cambrian schist. Most of the iron ore was mined out many years ago, exposing fluorspar under old workings. The fluorspar is white, usually amorphous, with iron staining in the fractures. Most of the fluorspar is located within an overturned fold, in a series of marbles and mostly schistose metamorphic rocks.

The tabular ore body lies in a synclinal trough in the overturned fold. The fluorspar structure is 1 to 1.5 km long, averages 1 to 3 km thick, and is 80 to 100 m wide, with 80 to 100 m of rocky overburden. Both the ore and overburden are brecciated, and the east end terminates against a fault.

Le Burc

The geologic environment consists of granite, schists, and other metamorphic rocks of Paleozoic age. The area has been subjected to intense folding and faulting.

The Le Burc deposit occupies a fracture running N 110° E, which dips 60° to the north. Mineralization extends 1,000 m, is 200 m deep. Crossfaults cut the vein into three sections. Gangue minerals are quartz with minor siderite and chalcopyrite. As mined, the ore grade will average 75 pct CaF_2, with some massive sections having grades up to 95 pct CaF_2. This is the highest grade fluorspar deposit presently being mined in France.

Montroc

The ore deposit consists of an east-west vein, with a branching vein striking N 60° to 70° E. The fluorspar occurs in massive crystals of white, green, and blue, with some disseminations of barite in them. The grade of the ore averages 54 pct CaF_2 with gangue similar to that at Le Burc.

Fontsante

Most of the minable fluorspar mineralization has been found in a series of east-west-trending vertical veins in granite gneiss. The mine is famous for being a source of cellaite (MgF_2). Cellaite, a white mineral, can easily be detected from the white amorphous fluorite by its color under black fluorescent light. Cellaite floats with the fluorspar and is desirable in making aluminum fluoride and artificial cryolite because it contains a slightly higher fluorine content than fluorspar.

Demonstrated resources are estimated at 380,000 mt. Ore grades 40 to 42 pct CaF_2 and 9 pct MgF_2, with the veins turning to barite and quartz at depth. The cellaite ranges from 2 to 16 pct. Depending upon which part of the vein is being mined, barite is not saved. Owing to the nature of the hard granitic country rock, very little core drilling is done, with reliance on surface exposures to locate veins.

Rossignol

The fluorite district is located on the northwest edge of the Massif Central in the extreme northern part of Limousin. It has classic fluorite veins in gneiss and mica schists on the periphery of granitic batholiths. The deposit, striking NW-SE, has an average thickness of 30 m and has been traced for 3 km in length and 100 m in depth. On the west the vein flattens, which gives it the appearance of a sedimentary deposit.

As at Fontsante, very little diamond drilling is done owing to the great expense involved. There is much dependence upon district experience and on continuity at depth and along strike. As of 1984, about 1.5 million mt was considered demonstrated resources, as defined by drifts and raises in the vein. Vein width and grade appears to improve with depth, with no weakening of the vein along strike. The average grade is 65.8 pct CaF_2. Barite is also recovered grading 16.9 pct $BaSO_4$, with 2.3 pct PbS.

Morvan District

There are about 10 economic and subeconomic fluorspar deposits in a 200 km² area around the Morvan Regional Park. Although there are some differences due to the lithologic nature of the host beds, the stratiform fluorite deposits of the sedimentary cover of the Morvan can be grouped as a single type. All of the stratiform deposits with large tonnages of fluorspar are found as limestone and sandstone replacement bodies in a thin stratigraphic inter-

Table B-7.—Deposits of the Morvan District, France (39)

Name	Resources, 10^6 mt	CaF_2 grade, pct	$BaSO_4$ grade, pct	Comment
Pierre Perthuis:				
Dampierre Forest	2.0	35.0	15	Mineralization in Chitry limestone.
Epenay Forest	1.8	38.5	9	
Pontaubert	1.7	38.0	10	In Chitry, much with no overburden.
Marigny-sur-Yonne	1.6	32.0	NAp	Associated with N-S fault where Chitry outcrops. Only deposit previously mined for metspar.
Ergeuil	1.0	40.0	NAp	Mineralization outcrops where Chitry is faulted, overlain with 0 to 20 m of Keuper marl.
Champallement and St. Reverien	1.0	NA	NA	Exploration incomplete, tonnage assumed for study.
Courcelles-Fremoy:				
Courcelles	.97	39.7	7.6	Mineralized horizon in calcarenite, 2 blocks split by narrow valley.
Fremoy	1.6	34.6	24	
Antully:				Mineralization in Triassic age sandstone close to granite or gneiss contact. Charbonniere needs more drilling.
Marquisat	3.5	34.0	NAp	
Charbonniere	1.8	34.0	NAp	
Total or weighted average	16.97	[1]35.6	[2]13.5	

[1] Weighted-average grade CaF_2 for all deposits excluding Champallement and St. Reverien.
[2] Weighted-average grade $BaSO_4$ for those deposits reporting a barite grade.

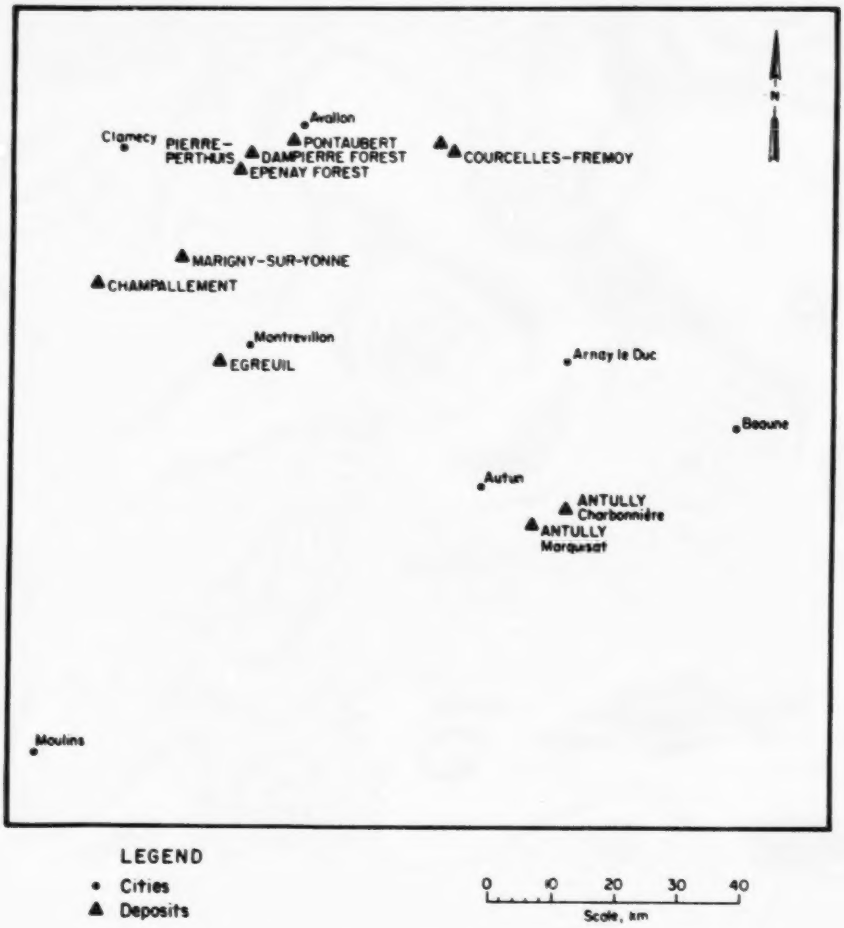
N
Avallon
Clamecy
PIERRE-PERTHUIS
PONTAUBERT
DAMPIERRE FOREST
EPENAY FOREST
COURCELLES-FREMOY
MARIGNY-SUR-YONNE
CHAMPALLEMENT
Montrevillon
EGREUIL
Arnay le Duc
Beaune
Autun
ANTULLY Charbonnière
ANTULLY Marquisat
Moulins
LEGEND
• Cities
▲ Deposits
0
10
20
30
40
Scale, km

Figure B-1.—Locations of fluorspar deposits in the Morvan District, France.

val between the weathered granite basement rocks and an impervious Mesozoic capping of marly clay. Fracture systems formed channelways for circulating mineralizing solutions, but vein fluorspar in the area is not important. Barite is an important coproduct but is considered a possible metallurgical separation problem (*39*).

The drill-proven demonstrated ore resources of the seven fluorspar deposits outlined for this evaluation total 17 million mt, grading between 32 and 40 pct CaF_2, with barite ranging from 5 to 25 pct $BaSO_4$. Four of the principal deposits located in the northwest Morgan district have been formed in the Chitry Limestone formation: These are the Pierre-Perthuis, Pontaubert, Marigny-sur-Yonne, and Ergeuil. Mineralization of the Courcelles-Fremoy deposit in the northeastern part of the district is represented by some calcarenites of uncertain age, and includes barite as well as fluorite. The two deposits at Antully are in the east-central portion of the Morvan in Triassic sandstone overlying the Chitry (*39*).

Table B-7 is a deposit listing for the Morvan District, and figure B-1 shows the relative location of these deposits. The areal extent of the ore bodies is between 25 and 50 ha with the single deposits of minable size being 5 to 15 ha, separated by intervals of low-grade, disseminated mineralization or completely barren zones. Ore body thickness usually runs from 2 to 4 m, with tonnages ranging from 1 to 4 million mt in each ore body. Most of the ore is siliceous (*39*).

Mining Methods

Producing Operations

In 1983, five vein mines were operating in France; two of the operations were open pits, three were underground operations. All of the mines, except Rossignol, were operated by Pechiney. Rossignol is owned by Societe industrielle du Centre (SIC).

At Escaro, mining is limited by the excessive overburden removal, which amounts to 30 to 35 mt waste for each metric ton of ore mined. High labor costs and a poor fluorspar market impair profitability at this operation, as do excessive overburden removal costs. The shattered nature of the overburden, however, precludes underground mining. Present open pit mining constantly intercepts previous iron mine drifts, usually over the fluorspar, which are now caved and full of timbers.

Mine production at the Le Burc operation was about 40,000 mt/yr in 1982, only 30,000 mt was produced in 1983 (*19*). The mine has recently switched from a shrinkage stoping method, which is quite labor intensive, to a method called "overhead slicing with inclined backfill." This method permits careful control of roof conditions and loose wall slabs. The method lends itself to safer mining practices because miners work on the fill close to the roof at all times. Broken ore, in steps, is removed by rubber-tired, front-end loaders, and fill is brought in to fill the void, which raises the work floor level. Overburden from nearby Montroc and heavy media tails are the source of the fill. There is still about 10-pct ore dilution, but this is an improvement over the old method.

In making metallurgical-grade gravel fluorspar, coarse fragmentation is desired and production of excessive fines is avoided. Working close to the back with this new method permits better size control. Even though there was a heavy investment in development for the transition, Le Burc management claims that mining costs, including recovery of such costs, has improved 67 pct, about half of which was from a reduction of labor cost per metric ton mined.

The production rate at the Montroc open pit mine was 120,000 mt/yr at the time of the site visit; production was split between Montroc's acid plant (100,000 mt/yr) and Le Burc's heavy media plant (20,000 mt/yr). Ore dilution of up to 50 pct is experienced in some areas of the mine, due to the presence of barren zones in the ore body. The average dilution was assumed to be about 20 pct.

Because there is a high hill next to the Montroc open pit, approximately 2 million mt/yr of waste must be removed, resulting in a stripping ratio of almost 17:1. Some of this overburden is hauled to Le Burc for use as stope backfill. Since Le Burc ships some of its ore to Montroc for concentration into acid-grade fluorspar, the waste is carried back in some of the same trucks used to haul ore to Montroc.

Mining at Fontsante and Rossignol is by traditional shrinkage stoping, with wooden chutes. At Fontsante, the shaft bottom arrangement and hoisting capacity are a production bottleneck, but reserves remaining as of 1984 are sufficient only through 1987, making further mine mechanization unlikely. Although subsidence at Rossignol is apparent at the surface, the mine is not located where it would damage structures, roads, or other improvements. Stope filling is not practiced at either site.

Morvan District

Each of the seven sites included in the Morvan District could warrant one or more open pit mines with moderate stripping ratios. Pechiney has proposed developing two open pit mines, not necessarily one at a time, on the Pierre-Perthuis ore body, and building a flotation mill nearby. The size of each mine will depend upon the needs and policies of Pechiney and whether or not it has a desire to develop export capabilities. Major considerations are how to contend with environmental concerns of the neighboring people who live near or have farms over the concessions; the minerals, however, belong to the state. For this evaluation, it was assumed that if all environmental problems could be overcome, a 5-yr lead-time would be required prior to production.

The mill would be of the smallest economic size, to prove to the community that the open pit mine and a flotation mill could operate in an environmentally responsible manner. Once the small operation has proven that mining can be done without permanent and unsightly damage, larger mining and milling operations would be planned (*36*).

This evaluation assumed that the pilot operation would mine 80,000 mt/yr, and would precede further development by 4 yr. Full-scale operations would mine 1 million mt/yr from several open pits, with reductions to 500,000 mt/yr during years when mining sites are moved from one location to another. This plan provides for production over 20 yr, but it should be kept in mind that resources are not fully defined and that environmental concerns may hinder initial development or further development.

Beneficiation

Producing Operations

The Escaro mill at Olette receives ore from an aerial tram and processes acid-grade fluorspar through grinding, flotation, filtration, and drying. The annual capacity is approximately 51,300 mt. Because of the ease in milling this ore, the grade of the flotation product is over 97 pct CaF_2, or acid-grade. A subacid-grade could be made for the ceramic industry if needed. A bagging machine is available with 1,000-to 1,500-mt bulk storage capacity.

All milling at Le Burc is done by heavy media separation. The plant can accept 60,000 mt/yr of Le Burc feed when operating at full capacity. An additional 20,000 mt/yr capacity exists to process Montroc ore to a ceramic-grade concentrate. The grades of metallurgical gravel range from 80 to 90 pct CaF_2.

The Le Burc plant produces about 24,000 mt/yr metallurgical-grade and about 5,500 mt/yr of ceramic-grade fluorspar from Montroc ore. Approximately 7,600 mt/yr of Le Burc ore is shipped to the Montroc acid-grade plant, which has a capacity of 60,000 mt/yr. The Montroc mill is a standard flotation mill, with drying and bagging facilities available.

The Fontsante ore grade is high enough that heavy media preconcentration is not required. After normal flotation, the filter cake is dried and a 97.5 pct CaF_2 product is recovered. Capacity is 44,800 mt/yr of acid-grade fluorspar. During processing, cellaite is saved, but the barite present is not. In addition, the concentrate contains between 1 and 15 pct MgF_2, which is considered a bonus. Although the presence of cellaite aids in the marketability of the acid-grade product, there was no known premium paid for it.

Milling at Rossignol consists of two heavy media concentration stages. The product is a metallurgical gravel fluorspar, grading 88 to 93 pct CaF_2. Production capacity is about 35,000 mt/yr, but slow markets have reduced output to around 23,000 mt/yr.

A market exists for a mixed barite and lead concentrate mixture for the making of heavy concrete used in making weights for pipelines for river crossings. The Rossignol mill produces about 6,000 mt/yr of this lead-barite concentrate. The barite is usually sold domestically; however, minor amounts are sold for use as drilling muds in the North Sea.

Morvan District

Owing to the locations of the resources, it may take four mill sites to serve the Morvan groups so that haulage from pit to mill can be kept to less than 10 km. For the purposes of this study, it was assumed that the proposed pilot plant built at Pierre-Perthuis would have a rated capacity of 230 mt/d. This acid-grade flotation mill would be located in a hidden valley in the northeast portion of the Dampierre block, just off the ore deposit. It was also assumed that two 1,500-mt/d mills would be built and placed into production 4 yr after initial production of the pilot plant. The order of development will depend not only on economics, but also upon the response of the surrounding communities. The two larger mills would each be relocated once in order to mine all of the presently outlined reserves.

The totally enclosed mills would contain all the operating sections: crushing, screening, classifying, grinding, thickening, conditioning, rougher flotation, primary cleaning, scavenging, final cleaning, pump storage tanks, filtration, drying, dust collecting, and concentrate storage, plus possibly a bagging facility. With an average feed of greater than 35 pct CaF_2, heavy media preconcentration is not justified, either from a cost viewpoint or a double tailing loss. Recovery has been estimated to be about 85 pct.

The Morvan acid-grade concentrate will eventually be needed to replace tonnages from current operations that are nearing depletion. Products would probably be shipped to the Pechiney HF plant at Ales. As France now imports much of its fluorspar requirements, there is also some pressure in favor of development of the Morvan properties to reduce some of the import dependency.

Transportation

All acid-grade fluorspar from Escaro is sold domestically, and is trucked and railed a distance of 225 km to the Usine de Salindres at Ales, which is the Pechiney chemical plant that makes AlF_3 and artificial cryolite for the use of Pechiney. If the product were to be exported, it would most likely be shipped through Port Vendres (70 km) for consumers in Italy or other southern destinations, and through Bordeaux (410 km) for shipments to northern Europe or the United States. Fluorspar concentrates produced at Montroc and Fontsante are also sent to the Pechiney's HF plant in Ales. Any concentrates from the proposed Morvan District headed for export would probably be shipped from the port at Bordeaux for northern destinations, or from Port Vendres near the Spanish border for southern destinations.

Metallurgical gravel from Le Burc is trucked directly to steel mill consumers in northeastern France, or to the railhead at Albi. For Rossignol's metallurgical gravel and lead-barite products, transportation costs are the responsibility of the consumer; trucking is available for the 25 km to the railhead at Argenton. Approximately 85 pct of the fluorspar produced is exported to West Germany's steel mills in the Rhine Valley, a distance of about 650 km.

ITALY

Geology

Mineraria Silius S.p.A.

Mineralization at the Mineraria Silius S.p.A. mines is considered to be hydrothermal in origin, centering on two vein systems named "San Giorgio" and "San Giuseppe." The veins contain fluorspar, barite, galena, some sphalerite, calcite, and quartz, with some silver values in the galena. These veins are roughly parallel, 1 to 5 m wide. At 200 to 300 m deep they converge to form a single vein 4 to 6 m wide.

Demonstrated ore resources as of 1983 were estimated at 8 million mt with average grades of 38 pct CaF_2, 12 pct $BaSO_4$, and 2 pct Pb. The bottom of the mineralization has not been located, as underground drilling holes are still intersecting ore below the bottom level. Exploration is almost entirely done inside the mine, driving along strike of the veins and probing the bottom.

Domusnovas

The areas of interest include the Su Barracconi, Bega d' Aleni, Perda Niedda, and Rio Bolentino. The mineralization present in the area can be subdivided in the following types of deposition: vein mineralizations, often found in karst limestones; contact mineralizations; and alluvial mineralizations. Recent alluvials are the site of the biggest fluorite-barite deposit in the Su Barracconi area, and at Baga d' Aleni these minerals are deposited in recent alluvials and in limestone karsts.

Around the old Perda Niedda iron mine, the outcrops in the pits contain fluorspar with accessory iron and zinc minerals. The ore is seen to persist in several old galleries in the pit walls. Fluorspar is found as replacements in the fine-grained limestones at the Pilloni de Sa Figu workings.

Pianciano

The Pianciano deposit consists of soft, pyroclastic lacustrine muds and sands deposited in a bedded form as a seam at the foot of the Sabatini volcano. The seam is approximately horizontal and is relatively undisturbed. The deposit lies on a relatively flat base of weathered basalt. The top of the seam is irregular with vertical undulations due to compaction pressure. The overburden material is relatively soft and unconsolidated (*22*).

In 1973, on behalf of Soricom, the Bureau de Recherches Geologiques et Minieres (BRGM) of Paris carried out a drilling program exploring 1,000 ha of the property. Based on this, BRGM estimates 5.83 million mt of clayey ore and 9.43 million mt of sandy ore are present. This tonnage is considered as identified, with a composite grade of 34 pct CaF_2. Demonstrated resources are given as 5.15 million mt of clayey ore and 2.63 million mt of sandy ore with a composite grade of approximately 43.9 pct CaF_2 (*15*).

Mining Methods

The Mineraria Silius group includes three separate vein mines on the same mineralized ore zone 3.5 km in length and up to 500 m in width. In order of their development and direction from northeast to southwest, these mines are Genna Tres Montis, Muscadroxiu, and S'Acqua Frida. The Genna Tres Montis and Muscadroxiu are now joined on the lower levels and can be considered a single entity. S'Acqua Frida was not operating at the time of the site visit. The underground vein mines utilize sublevel stoping with filling, and operate at 370,000 mt/yr ore plus 20,000 mt/yr of waste. Stope filling allows a reduction in the size of the pillars and improves ground support. Major development included driving a belt slope from a loading station, near the bottom, to the surface. The belt drifts total about 1,900 m and will eliminate practically all ore hoisting. Project completion, scheduled for late 1984, will save an estimated $0.80/mt.

Smaller Silius operations and small privately owned mines operated by contractors also provide ore to Silius. An additional 100 mt/d is available from a small open cut mine on the Monreale property, which was previously worked underground by Silius. An additional 45,000 mt/yr from these small mines is processed by the Silius flotation plant.

For Domusnovas, it has been proposed that much of the surface ore be dislodged by shallow ripping. Some will have to be drilled and blasted. The shape, size, and location of the open pits will be ruled by blending decisions. The presence or absence of zinc, lead, and barite will also influence the location of the pits and the mill. Underground mining could take place following depletion of surface resources if further drilling proves substantial enough resources. A lead-time of 5 yr was assumed prior to development and production.

A strip mine is currently being considered for the Pianciano operation. This evaluation assumed a development lead-time of 4 yr prior to production. In order to insure optimum ore grade and consistent feed head for the mill, clayey and sandy ore will be stockpiled separately and blended to achieve a grade of 44.04 pct CaF_2 (*15*). In order to keep the ores separate, it has been proposed that a 25-by-25-m drilling grid should be maintained six months in advance of mining. Both ore types will be selectively extracted to avoid unnecessary mixing (*22*).

The ore would be ripped with bulldozers, rather than blasted, and a truck and loader fleet would be used to extract and transport the ore to stockpiles. It has been proposed that a contractor be hired for mining, but no decisions had been made in this area. A mining rate of over 484,000 mt/yr would be needed to achieve a 75 pct metallurgical recovery (*22*).

Beneficiation

Immediately adjacent to the Mineraria Silius mines is a heavy media plant that treats about 35 pct of the ore hoisted, at a rate of about 750 mt/d. Heavy media tails are used to backfill stopes and for road surfacing. The flotation mill serving all Silius operations is located in the village of Assemini, which is 16 km west of Cagliari and 55 km from the mines.

In the flotation sequence, a lead concentrate is obtained before the fluorspar flotation, then a barite concentrate is floated from the tailings of the fluorspar section in a separate section of the mill. There is a rotary kiln fluorspar dryer, two bagging machines, and 50,000 mt of bulk storage facilities for the filter cake. Briquetting roll presses are available for the metallurgical-grade. Trucking capacity to the dock is 2,000 mt/d.

Annual capacity of the flotation plant is 415,000 mt feed, resulting in 125,000 mt acid-grade concentrate and 25,000 mt metallurgical-grade fluorspar, along with lead and barite products. Over half of the acid-grade fluorspar (70,000 mt/yr) is exported via the port at Cagliari to customers in the United States (mostly to Alcoa, which owns an interest in Silius), West Germany (to Bayer, which also owns an interest), Norway, Great Britain, Japan, the Netherlands, the U.S.S.R., and others.

Silius-owned subsidiaries, Fluorsid S.p.A. and ICIB S.p.A., are located near Cagliari. Between them they consume 55,000 mt/yr acid-grade fluorspar for production of synthetic cryolite and AlF_3. Lead concentrates are trucked to SAMIM's lead smelter in Cagliari, and barite products are sold f.o.b. vessel at the port of Cagliari.

At Domusnovas, only a 1,000-mt test lot has been processed through the Silius mill at Assemini; however, there were no readily apparent problems in making acid-grade fluorspar from the ore. The relatively coarse grind may classify it as free-milling. There have been observations that some of the sites may be promising for producing metallurgical gravel fluorspar high in iron, but Silius has not shown an interest in that product.

Plans to build a mill and develop the mine await a more favorable fluorspar market and an improved economy. It is feasible that Silius would not build a separate mill at the Domusnovas site, but would develop the mine when its other operations become depleted and utilize its present mill at Assemini.

Metallurgical research has determined that the Pianciano ore will be very difficult to treat by flotation into acid-grade fluorspar because of the very slimey nature of the ore and the various interfering minerals such as barite. Soricom is now convinced that a metallurgical-grade product made without flotation upgrading is the most feasible alternative for this deposit. One product possibility would be a 55-pct CaF_2 briquette for use as a flux. Briquetting could be done on site.

Soricom, along with BRGM, developed a unique beneficiation process that has subsequently been refined by various other parties. "The flowsheet for the BRGM process involves an initial feed preparation stage in which the ore is slurried and dispersed, followed by a preconcentration stage using hydrocyclones and decanters, with a final concentration stage in centrifuges. After the centrifugal separation, the concentrate pulp is thickened and filter pressed to produce a filter cake which is then agglomerated into pellets using an extruder prior to drying and calcining" (*22*). The BRGM process has been further improved through pilot plant scale tests done in the United Kingdom.

Infrastructure

At Domusnovas, water could be a problem, as there is no water near the site. It would have to be pumped from several kilometers down in old mine shafts, and its reuse could present problems if sulfide and barite circuits were in use. A powerline extension would also be required, and improvements would be needed to the 5 km of access road as well. The proposed acid-grade concentrate could be trucked 11 km to the nearest rail siding at Murtas or directly to Cagliari. From Murtas, concentrates would be railed to the loading port at Cagliari for export.

Metallurgical-grade from the proposed Pianciano operation would probably be trucked to the rail siding at Bracciano, and then either railed to consumers in Italy and Europe, or railed 60 km to the port at Civitavecchia for export to other parts of the world.

SPAIN

Geology

Fluoruros

Properties held by Fluoruros are located south and east of the city of Gijon along an east-west fault zone cutting Mesozoic and Tertiary sediments, consisting mainly of limestome host rocks, with both bedded ores and veins developed. Fluorite replacement deposits in the limestone are usually capped with an impervious shale, as is common elsewhere in the world where bedded deposits are found, such as the Cave-in-Rock District of southern Illinois. The beds dip northward toward the Bay of Biscay. In the Caravia District, they may actually persist below sea level, but exploitation below sea level has not been undertaken to date.

Overall reserves are held as confidential; however, Fluoruros intends to continue to develop resources in the Collada and Caravia Districts. Recent drilling for the Norberto mine in the Caravia District has resulted in probable reserves of 3.19 million mt averaging 38 pct CaF_2 (*20*). For the purposes of this evaluation, production was assumed to continue beyond the next 10 yr.

Minerales y Productos Derivados, S.A. (Minersa)

Properties operated by Minersa are located in two fluorspar districts in Asturias Province in northern Spain. These are the Gijon, or Villabona-Arlos District, and the Caravia-Berbes District. Minersa's holdings in the Caravia District will be referred to as Ribadesella in this report to distinguish them from other companies' holdings in the same district.

The ore at Gijon is a continuation of the same belt of limestone beds paralleling the coast of Asturias and dipping seaward towards the Sea of Biscay. This area contains many gash veins that were worked from outcrops for many years; recently, however, extensive bedded replacement deposits have been outlined, and these constitute the major source of ore. The ores of the Asturias area contain no sulfides or barite.

Reserves at Minersa deposits are confidential, but for this evaluation it was assumed that ore from the Ribadesella and Gijon Districts would be sufficient to keep the Torre mill operating for more than 20 yr.

Minas de Orgiva (Minor)

The sediments of the Orgiva area are considered to be Triassic in age and the basic structure of the area is that of an anticlinorium composed of three large parallel anticlines. Sierra de Lujar ore bodies are located in an east-west mountain range that had very steep sides due to an overturned fold structure. The mining concession extends about 25 km along the mountain range, and contains 30 to 40 small mines. Fluorspar is found in bedded replacement wings off vein-type structures paralleling the strike of the mountain. The replacement zones are at limestone-dolomite contacts adjacent to faults.

Drill-proven demonstrated resources total 3.55 million mt with an average grade of 31 pct CaF_2. In addition to the in situ resources, 500,000 mt of dump material remains containing 16 pct CaF_2 and 0.6 pct Pb. The operation closed in 1983 as a result of labor disputes. It is assumed to have resumed production in 1985.

Mining Methods

Fluoruros operates the San Lino open pit mine in the Caravia District and is developing the Norberto room and pillar mine in the Eduardo deposit. Contractors load and haul ore to the heavy media plant in Espasa. The Norberto mine plans to have a production capacity in the range of 180,000 mt/yr (*20*). Near Callada, Fluoruros has a series of concessions and leases, and operates both an open pit and room-and-pillar operation. All ore is hauled to the wash plant in Collada.

Minersa initially operated the Mina Ana and Cueto de Laspra as two separate open pits; however, they have been mined to the extent that they are now one large pit. Mining is done by contractors and is purchased delivered to the Torre mill. In the future, underground room-and-pillar methods will probably be utilized to exploit the deeper portions of the resource. These deeper beds will be below sea level and may experience salt-water seepage problems.

In the Gijon area, Minersa employs contractors for mining. Room-and-pillar methods are used at the two producing operations, Moscona and Cucona. Development was underway at Ampliacion Margarita and Laconne, but only exploration drilling had taken place at Ampliacion Arlos. Both Laconne and Ampliacion Arlos are planned to be underground extensions of abandoned open pits.

Minas de Orgiva (Minor) has operated the Sierra de Lujar mines for lead since 1950, with fluorspar production beginning in 1978. The mines utilize room and pillar techniques. Many of the old rooms are filled with hand-sorted waste from the lead mining operations, and this waste often has a fluorspar grade high enough to be of interest. There are about 70 km of old drifts and two shafts left from previous operations that provide natural ventilation.

Beneficiation

There are three flotation mills in Spain; Fluoruros S.A. operates the Pinzales mill; Minersa operates the Ribadesella mill, and Minor operated the Orgiva mill, which was temporarily closed in 1983.

Fluoruros S.A.

Ore mined by Fluoruros in the Caravia District is fed through the Espasa heavy-media separation plant prior to shipment to the flotation mill at Pinzales. A small amount of metallurgical gravel is produced at Espasa, but the bulk is a middling product which is further processed to acid and ceramic-grade products at Pinzales. A grinding plant is planned at the Norberto mine (*19*).

Collada District ore is sent to a wash plant in Collada, which is located central to Fluoruros' holdings. The simple plant is used solely to deslime and preconcentrate ore to a small extent before shipment to the Pinzales flotation plant.

The Pinzales flotation mill has a crushing circuit, followed by a grinding circuit and the flotation circuit. The acid-grade filter cake is generated by the first cleaner. Concentrates continuing to the second cleaner are cycloned to produce acid- and ceramic-grade products to be dried.

Major consumers of Fluoruros' acid-grade filter cake are the United States and the U.S.S.R. Dried acid and ceramic products are shipped by rail to consumers in Europe, and metallurgical gravel is consumed by steel mills in northern Spain.

Minerales y Productos Derivados S.A. (Minersa)

Minersa operates the Torre Mill at Ribadesella, Asturias, Spain. At the time of the site visit, approximately one-third of the ore processed at Torre was from the Ribadesella area, and two-thirds was from Gijon. Prior to processing ore from Gijon, the mill often processed much lower grade ores and a heavy media plant was used to upgrade ores as low as 20 pct CaF_2. Blending ores from both districts has raised the feed head to about 33 pct CaF_2, and the heavy media plant is only used if the head drops below 25 pct. Four ball mills are currently in operation and a fifth is available if market conditions improve. About 30 pct of the mill's water requirements are supplied by clarified tailings water; fresh water is supplied from a nearby river.

If market conditions warrant, Minersa may build another flotation mill in the Gijon area, thus avoiding the costly 95-km haul to the Torre mill. All products are trucked to a railhead or to the Port of Aviles for export. Domestic consumption is minor, and most fluorspar is exported to U.S. and Western European consumers.

Minas de Orgiva (Minor)

Although closed in 1983 due to a labor strike, the mill operated by Minor produced an acid-grade concentrate, a subacid-grade concentrate, and a lead concentrate. The mill stages included crushing, grinding, and flotation circuits. Water was supplied from the Rio Guadalfeo, but reuse was not practiced. Acid-grade fluorspar was trucked 35 km from the mill to the port at Motril for export to consumers in the United States, Holland, Germany, and Italy. The subacid-grade was sold domestically to the ceramic industry, and lead concentrates were sold to Penarroya, Minor's partner.

UNITED KINGDOM

Geology

North Pennine Field

Fluorspar deposits of the Pennines in Northern England occur in limestones of Lower Carboniferous age. Although the area was developed in the 18th century for its lead and iron, it has also been the source of witherite and barite as well as fluorspar. The age of the mineralization is variable but most of the deposits appear to be of late Carboniferous or early Permian age.

There are important vein and replacement deposits in the Pennine ore field, as well as old mine dumps that are being reworked. Reserves of the Cambokeels mine, for example, are mostly stope filling and dump material. Most deposits, however, are found in the thin alternating limestones, sandstones, and shales of the Yoredale facies, and occasionally in the intrusive quartz-dolerite.

Reserves in the Pennine ore fields are only vaguely defined. In general, resources are large because the vein systems extend over 640 km^2 of property owned, or controlled, by Minworth. For this evaluation, resources were considered adequate to meet present production levels beyond the year 2000.

South Pennine Field

The South Pennine Field, or Derbyshire Fluorspar District, covers over 500 km^2 of the board axial region of the Derbyshire dome. The dome is capped with a Carboniferous limestone, flanked by the Millstone Grit series and Lower Coal measures, which are rarely mineralized. The principal host rock is the Visean limestone series, which is a sequence of limestones with interbedded chert and contemporaneous volcanics of Carboniferous age.

The dome is transected by east-west folds, accompanied by extensive faulting and jointing. In general, the fluorspar occurs as a fissure-filling, vein-type deposit. The main systems are called "rakes," and are generally vertical, vary in width from 1 to 10 km, and may extend several kilometers along strike.

The veins most commonly contain fluorite, barite, calcite, quartz, and galena. There are also some replacement ore bodies and pipes occurring at intersections of faults or joints. Stratigraphic control is important in bedded replacements, such as at Matlock, where the bedded replacement is in limestone immediately above a lava unit.

Ore is obtained from underground mines located on the Hucklow Edge, Longstone Edge, Long Rake, and Matlock area veins; and from open pits at Ashover and on Bonsall and Bradwell Moors.

Mining Methods

Minworth Ltd.

Minworth operations utilize sublevel, shrinkage, and open stoping techniques. The Blackdene mine is located next to the mill of the same name. Haulage from underground is limited to three 3-mt cars, because there is only room for three dumping bins on the surface. This is severely limiting when production rates are at or near capacity. The ore is dumped directly into the mill bins and supplies about 33 pct of the mill feed. The ore is high grade, 70 pct to 80 pct CaF_2, and is used to keep the mill feed above 40 pct CaF_2. Whiteheaps supplies another 33 pct of the feed for the Blackdene mill with ore grades of 40 to 50 pct CaF_2.

The Readburn mine (sometimes called Redvein) has a high-grade ore that is used primarily for blending to upgrade feed to the mill. This ore is usually stockpiled and used sparingly. The remaining ore processed through the Blackdene mill is purchased by Minworth from a number of tributor dumps in the Blanchard area. Most of the ore from this area contains too much lead to be acceptable as metallurgical-grade fluorspar.

The Groverake mine normally is the major supplier of ore to the Broadwood mill. It was on standby in 1983 until excess stocks were decreased. The Allenshead mine is along the famous "Slitt" vein systems, formerly the most important lead-producing area of the United Kingdom. These mines contain numerous vertical shafts and mineralized structures and large dumps high in fluorspar values. Declines are planned to provide access to the reserves under the lead mine stope areas.

The Cambokeels mine provides substantial amounts of feed to the Broadwood mill from its old dumps and stope fillings from abandoned lead mines. New workings are developed as shrinkage stopes, and a new decline is being developed to penetrate a dolerite sill.

Laporte Minerals

Laporte operates an underground mine at Sallet Hole on the Longstone Edge vein system. Millstone Grit does not cover the limestone in this area, so the structures extend to the surface; open pit operations were previously performed at these sites.

The Ladywash operation was placed on temporary care and maintenance in 1979 due to deteriorating ground support conditions and rising mining costs. Ladywash workings are in the Hucklow Edge and Old Edge veins. These veins are overlain by Millstone Grit and were mined by sublevel open stope methods. Ore was recovered from old stope fillings and surface dumps from ancient mining operations, but remaining resources of these types are too low in grade to be commercially recoverable. Major ore reserves do exist to the west, in undisturbed Hucklow Edge, and at depth below haulage levels.

Over one-third of the ore supplied to the Cavendish mill is produced at Sallet Hole; another 25 pct is produced from the Raper Mine on Long Rake, the Masson Mine at Matlock, and the presently inactive open pit operations at Ashover and on Bonsall and Bradwell Moors. The remaining ore requirements are met by tributors operating small mines on both private and Laporte-owned land.

Beneficiation

The Blackdene mill processes about 500 mt/d, and produces an acid-grade fluorspar and a lead concentrate. Feed grades average 55 to 60 pct CaF_2 and 2 pct Pb. The flotation concentrate averages 98.7 pct CaF_2, with no subgrade middling product. A large flash dryer is used prior to storing the concentrate in 120-mt tanks. The concentrate may be briquetted, if required.

Ore from the Groverake, Allenshead, and Cambokeels mines is processed at the Broadwood flotation mill near Frosterly. The mill has a rated capacity of 400 mt/d and produces acid- and metallurgical-grade fluorspar concentrates and a lead concentrate. Metallurgical gravel is only produced when the lead content of the ore is low enough to meet requirements of the steel industry.

After heavy-media separation, the concentrate is fed to the ball mill, then to a flotation circuit. When metallurgical concentrates are produced, they are recovered after heavy media separation. Broadwood's acid-grade concentrate is made to meet the specifications of Chemical Industries, Ltd. (ICI), its primary customer. Rarely produced metallurgical products average 80 pct CaF_2 and are sold to domestic steel producers.

Laporte Minerals

Laporte operates the Cavendish fluorspar mill near Baxewell. Ore is delivered to the 100,000-mt-capacity blending yard quite muddy, requiring log-washing prior to crushing. After crushing, the plus 40-mesh fraction goes to heavy media separation where ore is upgraded to about 35 pct CaF_2. The minus 40-mesh material is deslimed in a thickener before ball milling. A limestone heavy media tailing is marketed as a road rock to the Peaks National Park Service.

After conditioning, the pulp proceeds to lead flotation, then to fluorspar flotation, and finally to barite flotation. Concentrates are filtered, but only fluorspar and barite are dried. Bagging equipment is available for the ceramic and barite products.

Infrastructure

Water for mill facilities is pumped from the shafts of deep abandoned lead mines. Laporte has reuse water available for operation of the log-washer. Tailings pond management is closely watched so that the ponds are out of sight of tourists. All mine and mill structures must conform to the 18th century architecture of the surrounding village, and stone fences must be left intact.

Transportation

Acid-grade fluorspar from the Blackdene mill is predominantly sold to domestic chemical and ceramic industries. Most of the products are consumed by industries in metropolitan Newcastle, a distance of 70 km by rail, from the siding in Durham. Acid-grade concentrates from the Broadwood mill are delivered 350 km by rail from the siding at Durham to ICI's Mond Division in Cheshire. The lead concentrate is shipped to Antwerp, Belgium, for smelting.

Fluorspar concentrates from the Cavendish mill are delivered throughout England in bulk trucks. Consumers are Laporte's own chemical plants in Rotherham and ICI's Mond Division, located in Cheshire. Barite products are trucked about 250 km to the Newcastle area for use in North Sea drilling projects, and the lead concentrates are trucked 150 km to the port of Kingston for export to smelters in Antwerp, Belgium. The road aggregate is sold to the Peaks National Park Service.

MEXICO

Geology

Zaragosa-Rio Verde District

This evaluation looks at the Las Cuevas, El Realito, and El Refugio mines of this district. The principal fluorspar ore deposits of the Zaragosa-Rio Verde district are limestone replacements along a volcanic intrusive contact, in rough irregular tabular shapes. At Las Cuevas, they range in size from 15 to 40 m in length and roughly 75 to 100 m in width. The bottom of this deposit has not yet been determined.

Mineralization occurred during the major Cenozoic volcanism of northern Mexico (*34*). The Las Cuevas deposit lies along the Santa Maria River trend of faulting between Lower Cretaceous limestones and Tertiary rhyolite. The fluorite replaces limestone and fills the open spaces with only minor calcite and silica, which results in an unusually high deposit grade. Silica content increases towards the rhyolite side. A hydrothermal origin is indicated with volcanic rocks being considered as the fluorine source and limestones as the calcium source. Other fluorite ore bodies along this same trend include La Consentida, El Realito, and El Refugio. Each of these was also hosted by the same reef-forming Cretaceous limestones in contact with Tertiary volcanic rocks.

The average in situ ore grade for the Las Cuevas deposit is about 85 pct CaF_2 with no sulfides or barites associated. Demonstrated resources as of 1982 were reported as 14.5 million mt using a cutoff grade of 70 pct CaF_2. This cutoff is due to mill headfeed requirements. The unusual purity of the fluorspar in the deposit allows crude ore to be sold directly as metallurgical-grade after crushing and screening to remove fines and oversize lumps (*17*).

The Las Cuevas mine area contains a limestone surface exposure of about 2.5 km^2, which has been denuded of its former rhyolite cap. Much of the remaining concession area is covered with rhyolitic volcanics and will require more extensive geologic exploration to determine the presence and extent of the ore.

El Refugio mine is in a chimney-type deposit in limestone adjacent to a rhyolite contact zone, with hydrothermal replacement of the limestone by fluorite, and fluorite void filling. For this study, resources at both El Refugio and El Realito were assumed to be sufficient to sustain production through the year 2000. It was also assumed that production at El Refugio could resume in 1985 if market conditions improve. The average ore grade of the two mines is about 75 pct CaF_2.

El Realito mines are in three chimney-type limestone replacement bodies on the Santa Maria fault zone. The surrounding wallrock consists of a strong limestone on the northeast wall and a weak, shattered and altered rhyolite on the southwest wall. El Realito ore body has been the principal source of ore in the past, but 100 m to the northwest is the No. 4 ore body, which is partially developed and has been mined to the 250-m level. Another 50 m to the northwest is the Colonia ore body, which was under development in 1983. Nearby, the Los Colorados open pit mine is located in another chimney deposit. It is presently closed.

Minas de Navidad

The Minas de Navidad (Navidad y Anexas) fluorspar properties are located in an area of Tertiary volcanics estimated to be more than 1,500 m thick. They originally formed an extensive plateau, but the Nazas River and tributaries have cut deep valleys and canyons into it, resulting in local relief over 450 m. The Mesa de Rincon Colorado, where the major fluorspar veins occur, is a remnant of the original plateau.

The fluorspar veins on the Navidad properties occur as several veins in a series of steeply dipping, parallel fault fissures in rhyolite. The principal mineral-bearing veins form silicified ridges at the top of the mesa, with increasing fluorite concentrations at depth. In areas where ore-grade fluorspar (50 pct CaF_2) is found, veins exhibit strong zoning parallel to the vein walls, which are commonly kaolinized rhyolite. Good crystalline fluorspar is interspersed with friable "sugar spar," with colors of green, purple, and white most common. The center of the vein contains the principal diluents, including a clay seam with blocks of chert and rhyolite, minor calcite, and iron and manganese oxides.

Demonstrated resources were reported as 750,000 mt as of January 1982. Because of the hard nature of the ore, drilling is difficult and kept to a minimum. Additional resources have been found by cross-cutting on various levels and extending exploration drifts along structures and faults. The company also holds reserves at the inactive Mariposa property near Muzquiz, Coahila. The only mill in the Muzquiz area is operated by Fluorita de Mexico, and sales of ore to the mill, or tolling it, are not presently attractive.

Sierra de Santa Barbara

The Sierra de Santa Barbara, situated in the south end of the state of Chihuahua, includes the mining districts of San Francisco del Oro and Santa Barbara, where Zinc de Mexico S.A. operates. The stratigraphy of these districts is characterized by a unit of Mesozoic marine sediments overlain by a sequence of volcanics and continental sediments of Cenozoic age. These rocks are intruded by a series of alkalic and mafic dikes.

The districts are made up of a network of large veins. There are presently some 500 km of underground workings in the mines. The veins are hydrothermal in origin, in fissure fillings, with widths averaging one meter. The most common ore minerals are sphalerite, galena, and chalcopyrite. The gangue minerals are quartz, calcite, fluorite, and various other alteration silicates. In addition to the veins, replacement bodies are also found, in which the veins appear to have furnished mineralizing fluids that replaced chemically favorable strata, such as slightly dolomitized calcareous shales (*24*).

Resources at Minera San Francisco del Oro S.A. are contained in a small amount of old tailings and in ore yet to be mined for its metal content. As it is uneconomical in narrow-vein mining to block out large reserves in advance, the long history of production (since 1629) allows a safe assumption that resources are sufficient to supply at least 5 to 10 more years of production. For this evaluation, resources were considered sufficient to continue production into the early 1990's. The grade of the tailings processed averages just over 13 pct CaF_2.

Resources at Zinc de Mexico S.A. are from three major sources. These include the remaining flotation tailings at Parral, where all mines have become exhausted; substantial tailings at the Santa Barbara unit southwest of Parral; and fluorspar contained in ore reserves yet to be mined for metals at Santa Barbara. If fluorspar market conditions warrant, a new fluorspar recovery unit may be activated at Santa Barbara. Overall, the Santa Barbara operations could supply an identified resource of about 43 million mt of tailings for reprocessing. Current tailings from the Parral operations average 17.5 pct CaF_2, and for this evaluation it was assumed that as of 1982, approximately 3.9 million mt of tailings remained from the Parral operations.

Fluorita de Mexico

The ore bodies of Fluorita de Mexico are flat-lying replacements of limestone underlying the Del Rio Shale. Seams of rhyolitic dike rocks lie in the fluorspar beddings in some places, indicating a relationship to a volcanic source. To date, no diatreme or volcanic pipe has been located to confirm this, however.

The fluorite mantos of northern Coahuila are typically elongated, flattened troughs. The tonnage of fluorspar in each manto ranges from 1,000 to 8,000 mt; and there are hundreds of them, many of which outcrop where they can be mined by hand. Ore resources are delineated in two areas: Buena Vista, and La Encantada. Another former mining area, El Tule, has recently been acquired, but has not undergone exploration yet. Demonstrated resources at other ore bodies are considered sufficient to maintain production beyond the year 2000.

Pico de Etereo Mining District

Fluorspar is the only mineral of economic value found in the Pico Etereo mining district; La Domincia S.A. operates in this district. Four types of deposits are included in the district: karst collapse with limestone breccia replacement, of which Cuatro Palmas is the best example; dome collapse, such as at Aguachile; arch collapse, found at the recently exhausted Malabrigo mine; and fracture filling in a breccia zone along a fault zone. All replacement deposits are in a Cretaceous limestone and closely associated with rhyolite intrusive rocks considered to be the source of fluorine-bearing fluids.

The Aguachile deposit is located in a dome collapse structure. Rhyolite intruded a Cretaceous limestone formation causing a dome, and when the rhyolite subsided, the dome collapsed. There was a resurgence of the intrusive accompanied by fluorine-bearing solutions. Fluorine in the solutions replaced the limestone breccia where there was an impermeable shale capping over the limestone.

Several new discoveries have been made in the district, but these properties are still undeveloped. (The potential for discovery of additional deposits is considered favorable.) For the purposes of this evaluation, a 1983 demonstrated resource of 2.17 million mt has been assumed. The ore grades have averaged 80 pct CaF_2, with 4 pct SiO_2 and 11 pct $CaCO_3$, and the cutoff grade for the resources is 60 pct CaF_2, as that is the mill feed requirement at this time. This cutoff grade should be kept in perspective when considering the potential for resources at lower grades. The Aguachile ore contains minor quantities of beryllium oxide that are not recovered, but are stored in the tailings pond as property of the Mexican Government.

Mining Methods

Historically, a number of Mexico's fluorspar mines utilized open pit methods; currently most utilize shrinkage stoping or room and pillar techniques. Las Cuevas utilizes specially developed shrinkage stoping techniques followed by induced caving to recover its relatively weak ore. The method involves mining narrow, ore-filled stopes for the purpose of establishing lines of large vertical pillars throughout the width of the ore body and over a predetermined length. Narrow, vertical, curtain pillars, extending from wall to wall and from level to level, are left between the stopes to be recovered later from a lower level. The pillars represent about 50 pct of the ore in the stope. Rock support is required only in small areas and is usually controlled with shotcrete. Mine production currently comes from the E and G ore bodies, and capacity in early 1982 was about 1,920 mt/d of ore and waste hoisted. Expansion plans call for a new shaft to service the 280-m level of the G ore body.

Mine production capacity at El Refugio is rated at 650 mt/d, but current market conditions have recently restricted output to 400 mt/d. Penoles temporarily closed the mine early in 1984, but for the purposes of this study, a future production rate of 400 mt/d was assumed.

Ore was extracted using post-pillar cut-and-fill mining methods. The mine is partially under the Santa Maria River, and generates 700 gal/min of water under normal conditions. More water is generated when the river level is high. Three pumps on the 2d and 4th levels, and a gathering pump on the 5th level, handle the water, which is discharged into the river. Over 60 pct of the water comes from the newly opened P-90 ore body, where the water has not been drawn down yet.

Fluorita de Rio Verde utilizes post-pillar cut-and-fill and open pit mining methods at the El Realito mines. Production averaged over 155,000 mt/yr between 1980 and 1982. Current production rates are somewhat lower because of the slow markets, but future capacity is projected at 192,000 mt/yr.

The Navidad ore bodies began underground production in 1976. Design capacity is 117 mt/d ore and 49 mt/d waste, but production has averaged 50,000 mt/yr in recent years.

Development efforts by Fluorita de Mexico over the past few years have been directed toward increasing mechanization at the Sabina mine and reducing the dependence on ore purchased from contract miners. In the past, up to 90 pct of the ore treated at the mill was purchased from contract miners. Sabina is developed for room and pillar mining and design capacity is 240 mt/d, although this rate has never been achieved.

La Domincia operates two mines in the Pico Etereo Mining District. The Cuatro Palmas mine is a cylindrical open pit about 100 m in diameter and about 100 m deep, with nearly vertical walls. Access is gained by a spiral ramp excavated in the limestone wall or in ore where portions of the limestone wall were replaced with fluorite. Over 90 pct of the ore was benched in open pit fashion from the center of the deposit. Side passages have been excavated into the manto extensions using room and pillar techniques.

The Aguachile mine was operated as an open pit from 1969 until 1981, and was the major source of ore for La Linda mill. In 1981, underground development was initiated, and at the time of the site visit in 1982, about 30 pct of the ore was recovered from the open pit, 60 pct from sublevel stoping and driving ramps in ore, and the remaining 10 pct was from room and pillar mining. Open pit mining is being phased out.

Tailings Processing

Minera San Francisco del Oro S.A.

In 1961, the Minera San Francisco del Oro operation was the first in the world to economically produce acid-grade fluorspar concentrates from tailings of a sulfide beneficiation process that contained less that 15 pct CaF_2 (*24*). The original flotation plant, built in 1934, was modified to recover fluorspar from low grade tailings in 1961 and was completely replaced in 1974.

Table B-8.—Annual production of fluorspar concentrates for Las Cuevas, 1975-83 (*17,34*)

	CaF$_2$, mt	
	Acid	Metallurgical
1975	66,586	250,580
1976	77,918	226,157
1977	88,393	261,113
1978	119,412	234,426
1979	143,726	275,071
1980	158,968	296,186
1981	186,452	393,843
1982	173,400	174,901
1983	156,991	0

The current fluorspar flotation plant at Minera San Francisco del Oro has a rated capacity of about 5,000 mt/d (*24*). Tailings from the sulfide operations and old tailings are processed together; the old tailings contain an average zinc grade of 1.0 pct. About 700 mt of zinc concentrates are produced monthly through a special circuit at the fluorspar flotation plant (*37*).

Mining at Minera San Francisco de Oro is performed for the purpose of recovering lead, zinc, silver, cadmium, and gold; all mining costs are borne by the metal concentrates. Fluorspar is produced through flotation of the discarded sulfide tailings. As of 1982, two mines were in production, the Frisco and Clarines, and a small amount of additional tailings were available from the sulfide production dating back into the 1600's. The old tailings that are processed for fluorspar are recovered from tailings ponds with front-end loaders and off-road trucks.

Zinc de Mexico S.A.

Tailings treated by Zinc de Mexico S.A. are currently supplied from impoundments near the old La Prieta mine in Parral. Tailings were collected in these impoundments for over 50 yr; mining ceased in 1975. The tailings are cut down with two hydraulic monitors, then the material is collected in pump sumps and pumped directly to thickeners at the adjacent flotation plant.

At Zinc de Mexico, the use of repulping by means of the hydraulic monitor has proven to be efficient in maintaining a constant head feed to the fluorite circuit and maintains a constant percentage of solids in the holding tank. Production between 1968 and 1981 averaged 60,000 mt/yr of acid-grade and 14,400 mt/yr of ceramic-grade concentrates. As a result of the depressed ceramic-grade market, only acid-grade concentrates were being produced in 1982. Future production rates for acid-grade concentrates are projected to be about 74,000 mt/yr.

Beneficiation

Acid-grade concentrates are produced with normal flotation processes at all eight of the Mexican operations. Metallurgical-grade products are generally recovered through gravity separation, with some screening and hand-sorting for impurities. Metallurgical-grade products are shipped from Las Cuevas, El Realito, and Minas de Navidad. El Refugio was producing metallurgical- and ceramic-grade products up until Penoles temporarily closed its Rio Colorado operations in early 1984 (*18*). Production at all facilities has been dwindling over the last few years, a result of poor market conditions, and expansion plans have been put on the back shelf for the time being.

Table B-8 lists the annual production for acid- and metallurgical-grade fluorspar from Las Cuevas over the years 1975-83. Market conditions are readily reflected in these numbers. Notice that the dips in metallurgical-grade production in 1976 and 1978 correspond with drops in steel production during the same periods. The overall decline in production since 1981 is a result of oversupply and low prices. Production of acid-grade concentrates in 1983 was from stockpiled ore; only development ore was mined that year (*31*).

Adequate water is a problem for Las Cuevas and Minas de Navidad. Las Cuevas recently purchased a quarry near its mine at Salitrera because a fault that runs through the quarry is thought to drain water from the surface. Hopefully, drawing water from this fault will help alleviate the water constraints (*17*). During the dry season, Navidad supplements its normal supplies with three wells drilled downstream from its operations; some decanted tailings water is also used.

Penoles management is studying the economics of combining all milling at the present Alamos Mill operated by Fluorita de Rio Verde S.A. This would reduce the haulage distance from El Refugio from 70 km to 10 km, allow a reduction of personnel through the closure of the Rio Colorado mill, and provide opportunities to produce additional metallurgical-grade products from El Refugio ore. Trace amounts of arsenic in El Refugio ore may cause problems in blending the ores because it is undesirable in certain concentrate applications.

The Fluorita mill at Muzquiz has an installed capacity of 1,000 mt/d, but storage and shipping facilities limit the output to 100,000 mt/yr of dried acid-grade concentrate. Ore is blended at the mill yard to about a 1:1 ratio, Sabina ore to contractors' ore. The concentrate produced by Fluorita de Mexico contains the lowest amount of phosphorus in any fluorspar produced in Mexico.

Transportation

Fluorspar concentrates are transported by rail to domestic destinations, such as the HF plant of Industrias Quimicas S.A. in San Luis Potosi (city), and Quimica Fluor S.A. de C.V. in Matamoros, Tamaulipas. Concentrates are also railed to points of export including the port of Tampico, and cities such as Eagle Pass and Brownsville, TX, along the U.S.-Mexico border. Table B-9 shows the major reported destinations of most fluorspar concentrates leaving the mills. Metallurgical-grade concentrates exported through the port at Tampico are shipped to consumers in the United States, Canada, South America, Europe, and Japan.

The port at Tampico is antiquated in comparison to the modern, automated port at Durban, South Africa. Loading procedures are slow, and since shipments are usually contracted by time, this can be quite expensive. The metals and minerals quay has various types of cranes available, as well as a chute and conveyor belt system, and is equipped with grabs operated by cranes. The quay is 306 m long and 9.75 m deep. Modernization of the port facilities would help to improve Mexico's position in the world fluorspar market.

Fluorspar products from Las Cuevas are consumed domestically, acid-grade concentrates are consumed by Quimica Fluor, and all grades are exported to the United States, South America, Europe, Australia, and Japan. Penoles trucks acid-, metallurgical-, and ceramic-grade concentrates to storage slabs at Rio Verde, SLP. Filter cake is exported through Brownsville, TX, for barge loading or railing to various consumers in the United States. Products also

Table B-9.—Destinations of fluorspar concentrates produced in Mexico

Mill and city of origin	Destination	Mode
Las Cuevas: San Luis Potosi	Matamoros, Mexico	Rail.
	Tampico, Mexico	Do.
	Brownsville, TX.	Do.
El Realito: Rio Verde	Tampico, Mexico	Do.
	Brownsville, TX.	Do.
El Refugio: Rio Verde	Tampico, Mexico	Do.
	Brownsville, TX.	Do.
Minas de Navidad:		
Rodeo	Bermejillo, Mexico	Truck.
Bermejillo	Brownsville or El Paso, TX[1].	Rail.
Fluorita de Mexico: Muzquiz	Eagle Pass or Brownsville, TX.	Do.
La Domincia: La Linda	Marathon, TX.	Truck.
San Francisco del Oro: Hidalgo del Parral	Matamoros, Mexico	Rail.
Zinc de Mexico: Hidalgo del Parral	San Luis Potosi, Mexico	Truck.
	Point Comfort, TX.	Do.

[1] Enters United States through Matamoros, Mexico.

exported to various steel and HF plants in Canada, Poland, and Japan.

Fluorita de Mexico's acid-grade filter cake is stockpiled at the mill and distributed to various consumers. Several small companies purchase 250 to 300 mt of bagged concentrates monthly, the remainder is sold through International Minerals Co. (IMC) in New York. La Domincia's acid-grade fluorspar is trucked to Marathon, TX, where it is purchased for DuPont's HF plant in Houston, TX. Two-thirds of Zinc de Mexico's acid-grade concentrates are railed to the Alcoa aluminum smelter at Point Comfort, TX, and the remainder is railed to Industrias Quimicas S.A. at San Luis Potosi, Mexico.

UNITED STATES

Geology

The following discussions will divide the U.S. fluorspar esources into two categories. The first section deals with he geology of domestic properties considered to be eserves. These are the six currently producing (developng) operations included with the world reserves of this tudy. In order to protect individual property confidentialiy, all other domestic fluorspar resources will be briefly iscussed in the Resource section. The total amount of emonstrated contained fluorspar in all categories is curently recognized as part of the domestic reserve base (33 illion mt).

eserves

linois

Four properties are located in the Illinois-Kentucky uorspar district. The district is characterized by a northest-trending structural arch that ends near Hicks Dome. A stem of faults crossing the arch from south west to northst has formed a series of horsts and grabens. The grabens e transected by northwest-trending faults and joints. icks Dome is transected by northeast faults and a series of dial faults on the northwest. Igneous rocks are present in e district as dikes, small plugs, and thin sills. Most ore in e district occurs as vein or bedded deposits and is sociated with joints and faults in Mississippian rocks.

Mineralization at Henson occurs as a vein deposit rmed by fissure filling and replacement of country rock by grating hydrothermal solutions. Impermeable shale beds overlying rocks limited the upward movement of migrating fluids. Joints and faults facilitated fluid movement. The presence of permeable limestone on at least one wall is a typical feature associated with deposits of this type.

The Denton and Annabell Lee deposits were formed by replacement beds of Mississippian age limestone. The Bethel Sandstone overlies the limestone. Barnett is also a vein-type ore deposit associated with the Rock Creek fault system. Two parallel veins are included in this complex. Principal ore mineral is fluorite, with barite, sphalerite, and galena. Calcite is the principal gangue mineral.

Nevada

The Crowell mine is located in a highly faulted part of a late Cambrian member of the Nopah Formation. Two faults control ore deposition; a northeast-trending fault dips vertically or steeply eastward, and a northwest-trending fault dips gently to the northeast. Ore is more dependent on the later set of faults, with ore shoots bounded by gouge zones of these faults. The factured dolomite is almost completely replaced by fluorite.

Fluorite mineralization, occurring as hydrothermal replacement in dolomite, ranges in thickness from 3.7 to 23 m, but an estimated 60 pct of the ore is dolomite inclusions and barren limestone ribs of various thicknesses. The zone is intensely brecciated, but the mineralization is quite uniform between inclusions of dolomite. Mine-run ore averages 60 to 85 pct CaF_2, and dolomite is the chief gangue mineral.

Texas

The Piasano fluorspar deposit is basically a fine-grained replacement ore of fluorite in the Buda Limestone. The minable occurrences are normally small, 9 to 5,400 mt, and occur as veinlets and collapse structures and as replacement bodies near rhyolitic intrusion contacts.

Some of the fluorite is high in uranium with the resultant radiation indicator of a very dark purple to black color. This led to testing that showed the ore to be anomalously high in uranium, thorium, molybdenum, and beryllium. The underground section, called the Rincon decline, has also shown signs of mercury in the form of cinnabar and molybdenum in the form of molybdenite and molybdite.

Resources

Alaska

Mineralization at the Lost River deposit occurs in varying amounts in acidic dikes. The deposit is in the contact metamorphic zone of altered limestone around and overlying the granite stock. Fluorite, cassiterite, wolframite, and beryl are the chief ore minerals.

Demonstrated resources total 25 million mt averaging 16 pct CaF_2. Other metallic minerals present in lesser amounts include sheelite, galena, marmatite, chalcopyrite, stannite, arsenopyrite, pyrite, molybdenite, stibnite and bismuthinite. Gangue minerals include quartz, topaz, tourmaline, zinnwaldite, clay, and lime-magnesium silicates.

Arizona

The McFadden Peak deposit occurs as a vein in an east-west trending fault. Mineralization is known to be continuous for over 2,000 m, but due to the narrowness and grade of the vein, not all of the ore is of commercial quality.

The host formation for the fluorspar is the Dripping Springs Quartzite, composed of silty, arkosic, and weakly metamorphosed sandstones, siltstones, and argillites. Large portions of the sandstone have been metamorphosed to quartzite by diabase sills.

Colorado

Resources in Jackson county (Northgate mill area), and Browns Canyon total 3.9 million mt averaging 45 pct CaF_2. The fluorspar deposits in the Northgate mill area consist of two separate zones of faulting known as the Fluorine-Camp Creek and the Fluorspar Zones. In the Fluorine-Camp Creek zone most of the wall rocks are schists and gneisses, although granite is present in some wall rock and arkosic rocks are found in the Fluorine No. 1 shaft. Deposits along the Fluorine-Camp Creek vein are generally wider than those on the Fluorspar Vein properties. Widths up to 12 m have been mined in the Fluorine Vein property, but the average width is generally less than 6 m.

Fluorite is the principal vein mineral in the Northgate area, although small amounts of calcium carbonate, iron, and manganese are present. The ore is relatively free of sulfides. Silica, in the granite wall rocks and in the form of chalcedony or silicified rock, is the most harmful impurity found in the ore and is so intimately associated with fluorite in some of the ores that satisfactory concentration is difficult. The amount of silica varies greatly at the various deposits.

Mineralization at the Crystal mine and Spar Claim group is restricted to fractures and faults within the later Precambrian quartz monzonite. A total of 48 veins containing fluorite mineralization have been mapped on the Spar Claim group. For the most part, they are associated with Tertiary faults which traverse both the quartz monzonite and the gneiss. The presence of chalcedony has been found to be a fairly reliable ore guide; fluorite mineralization is associated with every known occurrence of chalcendony in the Spar claim area.

At the Browns Canyon deposit, numerous ore bodies occur mainly as epithermal veins. The veins usually show abrupt slickensided walls with silicification and slight fluorspar replacement of wallrock. In some ore bodies, fluorspar has extensively replaced fault breccia. Maximum thickness of the fluorspar veins is 12.2 m, but the average is only 1.7 m.

Mineralogy of the Browns Canyon veins is predominantly fluorite and microcrystalline and chalcedonic quartz. Minor quantities of coarser grained quartz, opal, calcite, barite, pyrite, marcasite, black manganese oxides (pyrolusite, manganite, and psilomelane), iron oxides (limonite and hematite), and clay minerals (montmorillonite and kaolinite) also occur.

Idaho

The major geologic feature in central Idaho is the Bayhorse anticline, which trends N 10° W through Garden Creek and Daughtery Gulch. The Bayhorse and Kraken Hill deposits are located in this area. The principal deposit at Kraken Hill is a single fluorspar vein (Cachalot), deposited by fluid migration through solution cavities, leaving layered encrustations on both sides of the small voids or caves. The ore in the Bayhorse deposit was emplaced into the Bayhorse Dolomite as an open-space filling of collapse breccia features. Fluorite mineralization is widespread, but important mineralization occurs at two principal stratigraphic horizons. The ore grade averages 36 pct CaF_2 (*38*).

Ore resources for these deposits and Meyer's Cove total 3.7 million mt. The Myer's Cove deposit, located northwest of the Kraken Hill deposit in central Idaho, consists of a group of composite massive crystalline fluorite-barite-silica vein structures in fracture zones in tuffaceous volcanic rocks. Veins are localized along a complex zone of fracturing and appear to have been formed in an epithermal environment showing some replacement of the surrounding Tertiary age Challis Volcanics (*1, 33*).

Mineral deposition at Meyer's Cove is known to have a vertical range of more than 610 m. Coarse- to fine-grained quartz veins, containing up to 6 pct CaF_2, are common in the area and often merge with the fluorite veins (*33*). Mineral emplacement appears to have been more complete in areas of severe brecciation, where large pore spaces allowed enriched solutions to percolate through fractures. Fillings show banding and crustification indicative of an epithermal environment where deposition took place at shallow depth. The deposits are attributed to a deep-seated shear in the local basement rocks that allowed mineral bearing solutions to rise and be deposited (*1*).

Illinois, Kentucky

Deposits not included as reserves in Illinois and Kentucky have demonstrated resources over 5.2 million mt with fluorspar grades averaging between 20 pct and 30 pct CaF_2. The Minerva and Spivey mines are located in deposits formed when limestones were replaced selectively by hydrothermal solutions rising along fault and fracture zones. The Minerva ore body is tabular and multilevel, reflecting the ore occurrence in various replacement zones. The Spivey deposit is associated with the complex Goose Creek fault system. Both operations were closed in 1982 and were allowed to flood when pumping activities ceased in early 1984.

A number of fluorspar deposits are located in Crittenden and Livingston counties of western Kentucky and are part of the Illinois-Kentucky fluorspar district. Most are vein-type deposits associated with major fault systems such as the Babb fault system that extends more than 3.2 km across Crittenden and Livingston Counties, and the Tabb and Mexico systems that extend over 56 km across Crittenden and Caldwell Counties. Mineralization also occurs as fissure fillings and minor replacement of brecciated fragments and the wall rock. The ore and country rock may have been metamorphosed to various degrees.

Fluorite is the major ore mineral. Sphalerite and galena are also present in small amounts. The principal gangue mineral is calcite, with minor amounts of quartz and pyrite.

Nevada

Fluorite in the Fish Creek deposit occurs in quartzite and limestone of Middle and Lower Ordivician age. All Ordivician bedrock units in the Fish Creek area are mineralized. Fluorite is the principal ore mineral, with minor amounts of beryllium, molybdenite, and scheelite occurring in association with quartz and sericite; sphalerite has been found at depth. Mineralization occurs in veins, and as breccia filling and disseminated grains. Demonstrated resources are estimated to be 57.8 million mt grading 10.7 pct CaF_2.

At the White Pine deposit, fluorspar occurs as disseminated grains in silicified limestone and dolomite in Cambrian age rocks. A minor amount occurs in veins with quartz and feldspar. Trace amounts of copper, lead, zinc, silver, molybdenum, and tungsten occur in most of the fluorspar-bearing rock. The deposit occurs on the north flank of a northeast-trending anticline that appears to be plunging northeast. The deposit covers an area 1,100 m long and more than 200 m wide; demonstrated resources total 94 million mt at 10 pct CaF_2.

Several small fluorspar deposits in Nye County are included in the Nevada resource, total demonstrated resources are approximately 21.2 million mt. The largest of these are the Rainbow-Bruno-Nyco deposits which would be mined consecutively and utilize one mill. Rainbow and Bruno occurs in silicified bleached quartz latite volcanic breccia and welded tuff of Tertiary age. The fluorite mineralization is also of Tertiary age. Fluorspar occurs in steeply dipping veins and disseminated grains in silicified breccia and welded tuff. The area around the Nyco deposit has been brecciated, faulted, silicified, and pyritized. Fluorspar occurs in three veins in the breccia zone.

The Mammoth and Horseshoe deposits, also located in Nye County, occur in silicified limestone and dolomite associated with Tertiary rhyolite intrusive bodies. Silicified bodies of limestone contain a breccia core with fluorspar as a cementing material for breccia fragments. The most abundant fluorspar occurs in the replacement and banded ore bodies. A minor amount of fluorspar occurs in discontinuous veins and pods on fault contacts.

New Mexico

Three deposits were evaluated in New Mexico, with demonstrated resources just under 1 million mt. Bishop's Cap is a folded and faulted structure adjacent to the Organ Mountains. The rock types in the area are primarily massive and thin-bedded limestone, in part cherty, and interbedded shale (*23*). The fault systems contain veins in which some fluorspar is present, but fluorspar bodies are narrow and irregular except in the main vein. The main vein occurs along 400 m of strike length with an average thickness of 1 m. The depth appears to be greater than 100 m. The deposit contains an estimated 43 pct CaF_2, 25 pct SiO_2, 17 pct $CaCO_3$, and 6 pct $BaSO_4$ (*23*).

The Lyda-K mine produced small tonnages in the 1920's. Extensive exploration has been performed on the deposit, which has been idle since 1976. Fluorspar in the Lyda-K deposit occurs in a fault cutting Precambrian granite, schist, and gneiss. The fluorspar is found in a fissure vein averaging 2.7 m in width. The vein material is primarily jasper; it is more resistant than the surrounding granite and can be observed on the surface as a dikelike outcrop. The Lyda-K fault is offset approximately 38 m. Fluorspar occurs only along that part of the fault which is in granite.

The Blanchard fluorspar mine is located in the Hansonburg mining district on the edge of the Rio Grande Rift. Lead, silver, and gold were produced sporadically until the early 1950's. Fluorspar and barite were discarded with the tailings. This region is characterized by a series of normally faulted blocks, resulting in down faulting that increases progressively toward the center of the graben. These topographic lows have been laterally filled with Tertiary to Recent sediments derived from the adjacent uplands, as well as coincident rhyodacite to andesite volcanics (*3*).

Higher grade ore bodies are confined to vertical shear zones associated with normal faulting. Preexisting solution structures formed in the limestone beds and fracturing created during tectonism have resulted in more extensive, lower grade mineralized areas.

Tennessee

Deposits of the Sweetwater district in eastern Tennessee occur as stratabound, solution-collapse breccias in the Mascot Dolomite and upper Kingsport Formation. Ore horizons at the Stephens deposit are equivalent to those which host the ore deposits in the East Tennessee zinc district to the northeast. Individual ore bodies appear tabular in cross section and are connected on different stratigraphic levels by pipe-shaped, breakthrough breccia ore bodies. The ore bodies were thought to have formed from the influx of mineral-bearing fluids that mineralized previously brecciated area. Shaft-sinking and drifting underground failed to substantiate surface drilling results. Consequently, plans for development have been abandoned.

Fluorite is the major potential ore mineral with small amounts of sphalerite present. Barite is also present in highly variable amounts. Dolomite is the principal gangue mineral, with minor amounts of quartz, calcite, pyrite, marcasite, and galena.

Utah

Four deposits in southwestern Utah were investigated for fluorspar resources. These included the Blue Bell, Cougar Spar, J.B., and Utah properties. All of the deposits have produced minor amounts of fluorspar, the last shipment was from the Blue Bell operation in 1976. The highest grade and most accessible ore has already been extracted, and additional production is unlikely, except in a period of national emergency. The deposits occur in zones of fissured and brecciated formations caused by extensive faulting and volcanic action during the Tertiary Period. Diorites and quartz are common in these fault zones with the mineralized areas containing fluorite, quartz, and calcite.

Mining Methods

Producing Operations

The vein and replacement deposits of the Illinois-Kentucky fluorspar district utilize shrinkage stoping and room-and-pillar methods to extract the ore. Current producing operations include Barnett, Henson, and Denton Mines. The Annabell Lee came into production late in 1984. Production rates at producing operations range from about 150 to almost 275 mt/d. Common mine recovery is between 90 and 95 pct, with ore dilution of 10 to 20 pct. Ore is removed by drilling and blasting and is crushed underground. Rock bolts and timber are used as needed where ground failure is expected. Mine water is not a serious problem, it is gathered by gravity to collection sumps and pumped from the mine. Some of the water is used for cooling air compressors. After hoisting from the shafts, ore is trucked to the Rosiclare mill or the Knight Heavy Media plant.

The Cowell mine in Nevada is developed to a depth of about 180 m, and mining is done selectively in open stopes. This small operation mines approximatley 4,300 mt/yr ore. All ore and waste is drilled and blasted. Timber is required only in the shaft and ore chutes. Ore is hand trammed to the shaft, where it is loaded on an ore skip for transport to the surface. Most of the waste is used as backfill.

Open pit methods utilizing jackhammers and front end loaders to recover blasted ore are used at the Piasano mine in Texas. About 1,800 mt/yr ore is mined and hauled to the stockpile area for screening.

Proposed Operations

Presently idle and undeveloped properties in Kentucky have drawn sporadic interest over the years, and at present market prices are considered to be marginal resources. Extreme care would need to be exercised to economically produce fluorspar from these deposits.

The Bureau of Mines evaluation proposed that a number of mines be combined around centralized mills located at the Babb-Barnes and Marble deposits in Crittenden County, KY. Used equipment could provide cost savings, and consecutive mining of deposits would allow headframes and equipment to be moved from site to site. This could represent a significant savings, as the deposits are small and would have mine lives ranging from 1 to 15 yr. Mining methods appropriate to the deposit types include shrinkage stoping and room and pillar. It was proposed that mines serving each mill would have a combined mining rate of 750 mt/d to provide adequate feed to the mill.

In other parts of the country developed mines that are no longer in production would require various amounts of additional development and repair before they could be reactivated. Some of them would also require pumping, as they have been allowed to fill with water over years of disuse.

Most of the undeveloped domestic deposits evaluated were proposed to utilize shrinkage stoping and room-and-pillar methods. Several of the near-surface deposits would be operated as open pits during the initial stages and later as underground mines. Near surface deposits in Nevada were proposed as open pit operations. The Fish Creek and White Pines deposits would be immense, proposing to mine nearly 3 million mt/yr of low-grade ore. Lost River in Alaska is another large, near-surface deposit that would be mined wholly by open pit methods. Severe weather conditions at Lost River will hamper mining efforts, so economics is not the only factor affecting the chances of development.

Beneficiation

The Rosiclare mill at the southern tip of Illinois is the only operation currently producing acid-grade fluorspar concentrates in the United States. Inverness Mining is currently drying concentrates from South Africa at its Minerva mill. Owned and operated by Ozark-Mahoning, Rossiclare has a processing capacity of 544 mt/d and receives ore from the Barnett, Henson, and Denton Mines. Ore from the Annabell Lee operation is also expected to be processed at Rosiclare. The flotation mill produces acid-grade fluorspar, barite, lead, and zinc concentrates. The acid-grade concentrate is sold f.o.b. mill, as is the barite. Lead concentrates are smelted and refined domestically, as are most of the zinc concentrates. However, some zinc concentrates are shipped to Belgium for smelting.

Coarse material from the Henson mine is trucked to the Knight Heavy Media plant for concentration. Approximately 60 pct of the ore from Henson is processed to metallurgical-grade fluorspar and road rock. The remaining 40 pct (fines) is trucked to the Rosiclare mill for processing.

Ore from the Crowell mine in Nevada is sized and sold as run-of-mine ore to a nearby cement company. Bailey Fluorspar Co. purchases screened run-of-mine ore from the Piasano Mine in Texas.

The proposed Kentucky operations could utilize the existing Babb-Barnes mill, which was closed as a result of technical and economic problems in 1978. The mill would need to be redesigned, but capital expenditures would be much less than for building a completely new facility. A flotation mill near Mexico, KY was closed in 1973 as a result of ore depletion, and this facility could be refurbished and utilized for the deposits in the Marble area. Estimates suggest both mills would need to process an average of 750 mt/d ore to economically produce acid-grade concentrates. Small amounts of metallurgical-grade fluorspar, as well as barite, lead, and zinc, would also be produced.

The Northgate mill in Colorado is presently idle, but is largely intact. The facility could be reactivated if needed, or moved to a new location, a more likely consideration. Other acid-grade flotation facilities that are no longer active have been scavenged or left in disrepair and are really not available for production.

The Bureau of Mines has been testing new methods of flotation processing on ore from several of the Western fluorspar deposits. A new column method of flotation appears to be successful in producing acid-grade concentrates and byproduct beryllium from ores of the Fish Creek deposit in Nevada, and possibly could be used to produce a metallurigical-grade product from the Bayhorse ores (*11*). Transportation costs could keep these particular deposits from being exploited, but perhaps the new flotation technology will benefit other operations.

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